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GOVERNMENT OF INDIA

AERB SAFETY GUIDE

DESIGN OF ELECTRICAL POWER SYSTEMS FOR NUCLEAR POWER PLANTS

ATOMIC ENERGY REGULATORY BOARD

AERB SAFETY GUIDE NO. AERB/NPP/SG/D-11 (Rev.1)

DESIGN OF ELECTRICAL POWER SYSTEMS FOR NUCLEAR POWER PLANTS

Atomic Energy Regulatory Board

Mumbai-400094

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FOREWORD

Activities concerning establishment and utilization of nuclear facilities and use of radioactive sources are to be carried out in India in accordance with the provisions of the Atomic Energy Act 1962. In pursuance of the objective of ensuring safety of members of the public and occupational workers as well as protection of environment, the Atomic Energy Regulatory Board (AERB) has been entrusted with the responsibility of laying down safety standards and enforcing rules and regulations for such activities.

The Board has, therefore, undertaken a programme of developing safety standards, safety codes, and related guides and manuals for the purpose. While some of the documents cover aspects such as siting, design, construction, operation, quality assurance and decommissioning of nuclear and radiation facilities, the other documents cover regulatory aspects of these facilities.

Safety codes and standards are formulated on the basis of nationally and internationally accepted safety criteria for design, construction and operation of specific equipment, structures, systems and components of nuclear and radiation facilities.

Safety codes establish the objectives and set requirements that shall be fulfiled to provide adequate assurance for safety. Safety guides elaborate various requirements and furnish approaches for their implementation. Safety manuals deal with specific topics and contain detailed scientific, technical information on the subject. These documents are prepared by experts in the relevant fields and are extensively reviewed by advisory committees of the Board before they are published. The documents are revised when necessary, in the light of experience and feedback from users as well as new developments in the field. This safety guide specifically provides guidance on design of electrical power systems for safe operation of NPPs.

AERB issued a safety guide titled 'Emergency Electric Power Supply Systems for Pressurised Heavy Water Reactor' (AERB Safety Guide No. AERB/SG/D-11) in January 2002. This safety guide has been revised and is issued to reflect developments, which have taken place since then. Specifically, attention has been given to Post-Fukushima design upgradations, and design extension conditions. Also, Safety Guide is made a technology neutral document.

In drafting this guide, relevant International Atomic Energy Agency (IAEA) standards such as IAEA safety standards SSR-2/1(2016) on 'Safety of Nuclear Power Plants: Design' and IAEA Specific Safety Guide No. SSG-34 (2016) on 'Design of Electrical Power Systems for Nuclear Power Plants' have been used extensively.

The standards mentioned in the safety guide are acceptable to AERB. Equivalent standards other than those mentioned in the safety guide may also be acceptable if they provide at least a comparable assurance of safety intended in the standards mentioned in this safety guide.

Consistent with the accepted practice, 'shall' and 'should' are used in the safety guide to distinguish between a firm requirements and recommendations respectively. 'May' and 'Can' are used for desirable options. Bibliography is included to provide further information on the subject that might be helpful to the user.

The initial draft of the guide has been prepared in-house. Experts have reviewed the draft and the Advisory Committee on Nuclear and Radiation Safety vetted it before issue.

AERB wishes to thank all individuals and organizations who have prepared and reviewed the draft and helped in its finalization. List of individuals, who have participated in this task, along with their affiliation, is also included for information.

(G. Nageswara Rao)
Chairman, AERB

SPECIAL DEFINITIONS

(Specific for the Guide)

Alternate Power Sources [1]

Alternate on-site (e.g. Standby AC power sources / Main generators of other units at multi-unit site) or off-site (e.g. hydro/gas based power station) power sources which can be used to supply power to emergency electric power supply buses. These power supply sources are not part of the electrical power supply system of the NPP.

DEC Power Source

Power Source reserved for supplying power to the plant when there is total loss of power in all the emergency electric power supply systems during station blackout and also during other design extension conditions (DECs).

Electrical Grid

The part of electrical power system used for evacuation of power generated in NPP and receiving off-site power.

Electrical Protection System

A part of electrical system that protects an equipment or system. This encompasses all those electrical, electronic, mechanical, thermal, pneumatic devices and circuitry right from and including sensors, which generate a signal for protection.

Electrical Separation

Means for preventing one electric circuit from influencing another through electrical phenomena.

Emergency Electric Power System (EEPS)

That portion of electrical power system provided for supplying electric power to safety-related and safety systems of an NPP during its operational states as well as during accident conditions.

House Load Operation

Operation of a unit, isolated from the grid, which provides power supply only to the station loads from its main generator.

Islanding Mode of Operation

In the event of severe grid disturbances, to prevent catastrophic failure of the whole electric grid, a pre-identified part of the electric grid along with one or more generating units separates from the main grid and operates in an isolated mode with its voltage and frequency within acceptable limits.

Isolation Device

The device which isolates one circuit from others to prevent malfunctions in one circuit causing unacceptable conditions in the other.

Off-site Power Source

The electric power supply source located outside NPP and controlled by an agency other than nuclear power station operator.

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[1]The 'Alternate Power Source' as defined in this guide is different from 'Alternate AC Power Source' as defined in IAEA SSG-34. The equivalent of Alternate AC power source as defined in IAEA SSG-34 is 'DEC power source' in this Safety Guide.

On-site Power Source

The electric power supply source located within NPP and controlled by the nuclear power station operator.

Preferred Power Supply

Power supply from transmission system or main plant generator or a combination of both, to Emergency Electric Power supply system. Some portions of the preferred power supply are not part of the safety classification. (See Fig.2)

Standby AC Power Source[2]

Standby AC power source is an electrical power generating unit used in the event of grid supply failure, complete with prime mover, auxiliaries, generator, excitation system, automatic voltage regulator, control and monitoring devices and dedicated separate and independent stored energy supply for both starting and running the prime mover.

Station Blackout (SBO)

The complete loss of alternating current (AC) electric power to the essential and nonessential switchgear buses (i.e., simultaneous loss of the preferred power supply and unavailability of the emergency electric power supply system). Station blackout does not include the loss of available AC power to buses fed by station batteries through inverters or by DEC power sources.

Prolonged Station Blackout

The situation during Station Blackout, which can last from several hours to several days, where it may not be possible to recover the offsite power or on-site standby AC power sources.

Uninterrupted Power Supply (UPS)

A system that converts input AC electric power to controlled and filtered AC power that provides uninterrupted power supply for a defined duration, even with deterioration/loss of input AC power.

[2] The Standby AC Power Source usually consists of 'Diesel Generator'

CONTENTS

1. INTRODUCTION

1.1 Background

1.1.1 This Safety Guide is a technology neutral document issued in support of the safety requirements covered in safety codes on ‘Design of Pressurized Heavy Water Reactor (AERB/NPP-PHWR/SC/D Rev.2), ‘Design of Light Water Reactor (AERB/NPP-LWR/SC/D) and ‘Design of Fast Breeder Reactor based NPPs (AERB/NPP-FBR/SC/D)’, hereafter referred as AERB safety codes on design of NPPs. This safety guide predominantly refers existing safety codes for design of NPPs (e.g. PHWR, FBR and LWR based NPPs), guidance is also applicable to other NPP technologies.

1.1.2 This Safety Guide supersedes the AERB Safety Guide AERB/SG/D-11 ‘Emergency Electric Power Supply Systems for PHWR’ issued in January 2002. It takes into account, the national and international developments in the design of Emergency Electric Power Systems (EEPS) for NPPs and expands the scope to include all electrical power systems that provide power to systems important to safety under Design Basis Accidents (DBA) and Design Extension Conditions (DECs). It provides guidance on deciding the necessary characteristics of electrical power systems i.e. preferred power supply systems, emergency electric power systems and DEC power supply for nuclear power plants and of the processes for developing these systems, in order to meet the safety requirements as mentioned in Codes for design of NPP.

1.1.3 It may not be practicable to apply all the recommendations of this Safety Guide to Nuclear Power Plants (NPPs) that are already in operation or under construction. For the safety evaluation of such designs, it is expected that a comparison would be made with current standards, for example as part of the periodic safety review for the plant, to determine whether the safe operation of the plant could be further enhanced by means of practicable safety improvements.

1.2 Objective

1.2.1 The objective of this Safety Guide is to elaborate safety requirements set out in the AERB Safety Codes on design of NPPs and provide guidance for achieving compliance to these requirements.

1.2.2 It is intended for the use by designers, reviewers, operating organizations, involved in the design, operation, maintenance, modification, assessment, and licensing of NPPs.

1.3 Scope

1.3.1 This Safety Guide is applicable to all NPP technologies. The extent of the EEPS as given by classification of the electrical power systems, differs in accordance with the plant design. The minimum requirements for electrical power systems necessary at different voltage levels for maintaining defence-in-depth and diversity are outlined in this Safety Guide. In all cases, this Safety Guide should be used together with the plant’s safety analysis in order to determine the safety significance and importance of different power systems including their equipment. For example, in plants with passive engineered safety features, the classification of the electrical power systems may be substantially different from that shown in Fig 2.

1.3.2 The inputs to safety control and instrumentation power supply are derived from EEPS. These power sources are generally provided with battery backup. Details of these power supplies are covered in AERB safety guides on Safety Systems for Pressurized Heavy Water Reactors (AERB/SG/D-10) and Safety Related Instrumentation and Control for Pressurized Heavy Water Reactor Based NPPs (AERB/SG/D-20).

1.3.3 The Safety Guide is focused on Electrical Power Systems. Guidance on specifications of loads is not covered in the safety guide. However, the designers should ensure that the load specifications are prepared in accordance with the design guidelines of the electrical power supply systems provided in the Safety Guide.

1.3.4 While designing electrical power systems, potential interfaces between nuclear security and safety should be analyzed and addressed as applicable. Plant electrical power systems provide input power for plant security systems (e.g. fences, surveillance systems and entrance access control) etc. However, further detailed requirements are outside the scope of this guide.

1.3.5 The Safety Guide does not include requirements of non-electrical systems such as hydraulics, steam and gas turbine etc. if used as a diverse approach to supply motive force to any safety-related equipment.

2. ELECTRICAL POWER SYSTEMS AT NUCLEAR POWER PLANTS

2.1 General

2.1.1 Electrical power systems that supply power to systems important to safety are essential to the safety of NPPs. These electrical power systems include both on-site and off-site power systems (Fig 1). The on-site power systems and off-site power systems work together to provide necessary power in all plant conditions, so that the plant can be maintained in a safe state.

2.1.2 Electrical power systems should be designed to include various modes of interaction between off-site power and on-site power considering all states of the plant.

2.1.3 Electrical power system for NPP should be 'Robust' and should be 'Reliable' in all plant states.

2.1.4 Robust system should have:

a) Sufficient margins and built-in conservatisms such that equipment ratings, capabilities and capacities that are required to meet intended goals are not easily challenged;

b) Set points for equipment protection that are chosen to accommodate anticipated variations in the operation of on-site and off-site power systems;

c) Ability to support emergency operations involving sustained overload conditions or degraded voltage conditions and protective actions that are initiated when necessary to preserve the functionality of the EEPS.

2.1.5 System reliability should be achieved through proper implementation of the design, periodic testing, and maintenance to provide assurance that electrical power systems can perform their intended functions with a minimum of disturbances.

2.2 Off-site Power System

2.2.1 Off-site power system is composed of the transmission system (grid) which normally provides AC power to NPP in all modes of operation and in all plant states. It also provides transmission lines for power evacuation.

2.2.2 Off-site power system is part of the preferred power supply. It performs an essential role in terms of safety in supplying the on-site power systems with reliable power from multiple power sources:

a) Main generator/generator transformer (if GCB is provided) via unit auxiliary transformers

b) Grid power supply via the standby[3] transformer

2.2.3 A stable and reliable grid (with reliable generating stations, transmission systems and distribution systems) is fundamental to the safety of the NPP as it rapidly dampens the effects of grid perturbations in normal operation and minimizes the deviations in voltage and frequency in the connected electrical power system of the NPP. The transmission system operator has the responsibility of ensuring a reliable electrical power supply to NPP as well as transmitting its power to the electrical distribution network.

2.2.4 NPP should be designed in such a manner that it supports highly reliable operation of the grid system in accordance with Indian electricity grid code or bilateral agreements between NPP and transmission system operator.

2.2.5 Grid disturbances may challenge safety of NPP in its normal operation, anticipated operational conditions including accident conditions.

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[3] Standby transformers are used to derive power supply from the grid as an alternate to unit auxiliary transformers. For PHWRs, they are known as start-up transformers which share 50% load during normal operation. In NPPs, without GCB, start-up transformers are required for reactor start-up.

2.3 Station Switchyard

2.3.1 Station Switchyard is an interface between off-site and on-site power system. The operation of the switchyard equipment is generally under the control of NPP in co-ordination with grid.

2.4 On-site Power System

2.4.1 On-site power system is composed of distribution systems and power supplies within NPP. It includes the AC and DC power supplies necessary to bring NPP to a controlled state following anticipated operational occurrences or accident conditions and to maintain it in a controlled state, or a safe state, until off-site power supplies can be restored. The on-site power systems are separated or divided according to their safety significance into systems important to safety and systems not important to safety.

2.4.2 The major components of the on-site power system include the main generator, generator step-up transformer, unit auxiliary transformer, reserve/start-up/ standby transformer, standby AC power sources, DEC power sources along with protection relays and logic circuits and distribution system feeding unit auxiliaries, service auxiliaries, switchgear, batteries, rectifiers, inverters and/or uninterruptible power supplies, cables.

2.4.3 The design of the on-site power system should take into consideration of the limitations and capability of off-site power system in supplying reliable power to NPP and its impact on the nuclear safety.

2.5 Preferred Power Supply

2.5.1 The preferred power supply is the normal supply for all plant systems important to safety. It is, if available, always the first and best choice of power supply to the EEPS. The preferred power supply includes parts of both the on-site and off-site systems.

2.5.2 Preferred power supply system (Fig. 2) is composed of transmission system (grid), switchyard, main generator, distribution system up to the safety classified electrical power system.

2.5.3 The parts of the preferred power supply that are part of the off-site power system (e.g. the transmission system) are not plant equipment and are therefore not part of the safety classification for the plant.

2.6 Emergency Electric Power System

Emergency Electric Power System (EEPS) supply provides power to safety systems and engineered safety systems (Fig. 2). The EEPS is normally supplied by preferred power supply system. In case of unavailability of the preferred power supply, EEPS is supplied by standby (AC) power sources. DEC power supplies are required to feed specific loads during Design Extension Conditions (DEC). The power from DEC power supplies to specific load may be extended directly or through a portion of EEPS.

2.7 Alternate Power Supply

There may be some off-site power sources (e.g. hydro/gas based power stations), which can also be used to provide power supply to preferred power supply buses. Some of the on-site power sources (plant generator of other units, Standby AC power sources of other units) may also be used through inter-tie (at multi-unit sites) to increase the availability of power supply to electric power system buses. These are alternate power supply sources but not part of the electrical power supply system of the NPP.

2.8 DEC Power Supply

Several design measures are possible as a means of increasing the capability of the electrical power systems to cope with a station blackout. Provision of on-site AC power sources, which is diverse in design than standby AC power source is one of these design measures. These Power Sources are normally kept reserved for supplying power to the plant during total loss of power in all the emergency electric power supply systems that do not have battery backup

(Station Blackout), and other design extension conditions. The DEC power source is not susceptible to the events that caused the loss of on-site and off-site power sources.

2.9 Classes of Power Supply

Electrical power supply systems are classified into Class IV, Class III, Class II and Class I power supply systems according to the nature of power supply (AC or DC) and permissible power supply interruption period.

2.9.1 **Class IV Power Supply System -** The preferred power supply derives power from the grid, plant generator or a combination of these sources. This power supply is generally referred as Class IV power supply system and is interruptible for longer duration without affecting the safety of the NPP. Class IV supply system is normally used to provide power supply to emergency electric power system and non-safety loads.

2.9.2 **Class III Power Supply System -** AC power supply system normally fed from Class IV power supply system and backed up by Standby AC power sources is called class III power supply system. The NPP can tolerate loss of loads connected to this power supply system for a short duration which can range from seconds to few minutes as supported by the plant safety analysis.

2.9.3 **Class II Power Supply System -** Class II AC supply system derives the supply normally through DC-AC inverter fed by AC-DC converter connected to a Class III AC system. This system is backed up with batteries and provide an uninterrupted AC supply to the connected loads. The AC-DC converter normally supplies load through inverter and also charges the batteries which provides input to the inverter in the event of Class III AC power failure. During the failure of DC-AC inverter, the maximum interruption time for restoration of Class-II power supply is commensurate with the interruption time tolerable for the connected loads as governed by safety analysis.

2.9.4 **Class I Power Supply System -** DC supply system is normally supplied from AC power system of the EEPS through AC-DC converter (rectifier). In case of failure of AC power to rectifier, the batteries continue to supply power to the loads without interruption.

2.9.5 Though the classes of power supply mentioned in this guide are based on PHWR technology, the equivalent nomenclature for classes of power supply as applicable to the other reactor technologies is also acceptable.

3. SAFETY CLASSIFICATION AND SEISMIC CATEGORIZATION

3.1 General

3.1.1 A systematic approach should be followed to identify the structures, systems and components for electrical power system that are necessary so that items essential to fulfil the fundamental safety functions can be powered from electrical supplies of the appropriate safety class.

3.1.2 Safety classification and seismic categorization of components, structures and systems of electric power supply systems should be as per AERB safety guide on Safety Classification and Seismic Categorization (AERB/SG/D-1)[4].

3.1.3 Off-site power systems, switchyard and main generator systems also have an essential role in ensuring the performance of fundamental safety functions, but these systems generally are not classified according to the safety classification of the plant.

3.2 Safety Classification

3.2.1 For an NPP, the safety classification process of electric power systems should primarily cover:

a) The design basis of the plant and its inherent safety features;
b) All postulated initiating events,
c) The frequency of occurrence of the postulated initiating events.

3.2.2 The possibility that the failure or the spurious operation of an item important to safety may directly cause a postulated initiating event or make the consequences of a postulated initiating event worse should be considered when the list of postulated initiating events is established.

3.2.3 All electrical power system functions and design provisions necessary to achieve the fundamental safety functions, for the different plant states, including all modes of normal operation, should be identified.

3.2.4 The electrical power system functions should then be categorized on the basis of their safety significance, with account taken of the following three factors:

a) The consequences of failure to perform the function

b) The frequency of occurrence of the postulated initiating event for which the function would be called upon

c) The period of time following a postulated initiating event at which, or the period of time during which, the function will be required to be performed

3.2.5 The electrical power systems and components performing each function assigned in a safety category should be identified and classified. They should primarily be classified according to the category assigned to the function that they perform.

3.2.6 Equipment that performs multiple functions should be classified in a safety class that is consistent with the most important function performed by the equipment.

3.2.7 When assigning the safety classification, the reliability with which any failure in the electrical power system could be detected and remedied and the reliability of alternative actions possible should be considered.

3.2.8 The interface between the safety systems and systems of lower safety classification should be carefully designed to ensure that there is no adverse impact on safety equipment from non-safety-related equipment as a result of disturbances in the plant electrical power system.

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[4]The safety guide AERB/SG/D-1 is predominantly refers to safety systems of PHWR based NPP, however, the guidance is also be applicable to other NPP technologies

3.3 Seismic Categorization

3.3.1 Seismic categorization of components, structures and systems of EEPS should be as per AERB safety guide on Safety Classification and Seismic Categorization (AERB/SG/D-1).

3.3.2 Equipment used in preferred power supplies, switchyard and alternate power supplies should be seismically qualified to withstand seismic severity defined according to applicable Indian standards.

3.3.3 Equipment used in EEPS (e.g. Stand by AC power source, batteries, uninterrupted power supply, battery chargers, distribution systems, etc.) should be capable of fulfiling its performance requirements during and after design basis earthquake.

3.3.4 Specific portion of the EEPS that is used for supplying power from DEC power sources during Design Extension Conditions shall be capable of withstanding extreme seismic event[5] and should fulfil performance requirement after the extreme seismic event (Ref. AERB-NF –SG-S-11).

4. DESIGN BASES FOR ELECTRICAL POWER SYSTEMS

4.1 General

4.1.1 The design basis should be specified for each electrical power system of NPP. The design bases should specify the required functional tasks, the necessary characteristics, the performance objectives, the operating conditions and environmental conditions, and the necessary reliability.

4.1.2 The design bases should be confirmed when major replacements and major modifications of the electrical power system (on-site or off-site) as well as changes in loading are made and a cumulative evaluation is performed periodically, for example as part of periodic safety reviews.

4.2 Specific Design Basis

Power Quality

4.2.1 For each electrical power system in the plant, the voltage range and the frequency range including unbalance limits for the continuous operation of connected loads should be defined.

4.2.2 The permissible transient and quasi-stationary voltage range and frequency range for the continuous operation of connected loads should be defined for each electrical power system in the plant.

4.2.3 Transients that should be considered include the internal events and external events, including grid events, which are indicated in para. 4.2.5(d)(ii).

Operational events/ occurrences

4.2.4 The design bases should cover all modes of operation and should take into account all possible events that could impact the electrical power systems of NPPs, including:

a) Symmetrical and asymmetrical faults including open phase condition fault
b) Sub-synchronous resonance phenomena
c) Large motor starts
d) Momentary perturbations in the grid system, such as switching surges or lightning strikes
e) Capacitor bank switching
f) Loss of transmission system elements, including single phase open conditions
g) Formation of grid islands and resulting frequency excursions and voltage excursions.
h) House load mode of operations and resulting frequency and voltage variations

4.2.5 The design basis for each item important to safety should be systematically justified and documented. The documentation should provide the necessary information for the operating organization to operate the plant safely. The design basis should describe the following for each sub-system of electrical power systems:

a) The plant operational states in which the system is required: These include plant operation from startup to maximum authorized power with maximum auxiliary loading, plant shutdown from full power, and safe shutdown following a reactor trip and a DBA.
b) Voltage range and frequency range for continuous operation: These ranges define the operating requirements for equipment such as motors, inverters, battery chargers and valve actuators.
c) Capacity requirements: The equipment credited in the accident analyses normally defines capacity. Capacity, in terms of electrical equipment, includes for instance simultaneous start or re-acceleration of components, if applicable.
d) Steady state, short term operation and transient conditions to which the systems might be subjected when they are required to perform:
   i. Steady state conditions include, for example:
      - Voltage ranges and frequency variation for heavy load and light load conditions, for all plant states, and for house load operation where applicable;
      - Deviating grid voltage or grid frequency;

- Float voltage and charging voltage for DC power systems.

ii. Transient conditions include, for example:
   - Switching surges;
   - Lightning surges;
   - Voltage interruptions caused by electrical faults on and off the site;
   - Voltage sags and swells in conjunction with loss of load, motor starts, and clearing of faults on the on-site electrical power system or the off-site grid;
   - Variations and transients in voltage and frequency when the grid (and main generator) are affected by faults;
   - Harmonics due to switching surges or rotating equipment;
   - Faults in the transmission system or the on-site power system (all voltage levels) cleared by first step protection or backup protection;
   - Events involving loss of synchronization between the plant and the grid;
   - Single phase or multi-phase or ground faults in on site or offsite power systems;
   - Malfunctions of the main generator excitation system (high, low and loss of excitation);
   - Open conductors;

e) Variables to be monitored, such as the system voltage, the system current and the frequency, of the main bus bars: This includes variables necessary for monitoring during and following an accident.

f) Actuation conditions for operating standby electrical power supply: This includes variables that are used to initiate required actions.

g) Environmental and electromagnetic conditions to which components and cables will be subjected. Environmental conditions include:
   - Normal conditions;
   - Abnormal conditions;
   - Accident conditions;
   - Conditions deriving from natural phenomena.

h) Identification of all loads indicating safety classification and electrical characteristics: This includes motor input power at run-out when applicable.

i) Required performance characteristics of all components.

j) Requirements for maintenance and testing: This includes test acceptance criteria.

k) Protection schemes and coordination of protection: Protection schemes are to consider both symmetrical and asymmetrical faults.

l) Design acceptance criteria: It includes, for example:
   - Standards to be used or considered;
   - Requirements for design characteristics (e.g. independence characteristics, compliance with the single failure criterion and diversity requirements).

m) Reliability and availability goals for systems and key components: For example, the reliability of the standby power supplies:
   - Reliability and unavailability limits for systems and components may be specified by using probabilistic criteria, deterministic criteria (e.g. compliance with the single failure criterion) or both.

n) Voltage, speed, time to start and load, and other limits applicable to standby power supplies and their prime movers.

o) The maximum time for standby power supplies to start and to accept loading in a specified load sequence. The equipment credited in the accident analyses normally defines permissible starting time.

p) The required performance characteristics of standby power supplies, including the capability for no load, light load, rated load and starting load as well as, in certain states, overload operation for the required time periods.

q) The capability for step loading of the standby power supplies over the entire load range: The step load capability specifies the conditions of voltage and frequency that the standby power supply has to maintain in order not to degrade the performance of any load below its minimum requirements, even during excursions caused by the addition or removal of the largest load.

r) Conditions to be permitted to shut down or disconnect power sources for safety loads: This includes, for example, the need to protect equipment from catastrophic failures.
s) The minimum time for which on-site power has to be capable of operating independently of off-site power and without replenishing consumable items from off-site. This will be considered, for example, in setting the required capacity of batteries, emergency generator fuel and lubricating oil in storage, and the required storage of other consumables such as air filters.
t) The variables, or combination of variables, to be monitored.
u) The control functions required, and identification of whether actions are to be performed automatically, manually or both, together with the locations for the controls.

5. GENERAL DESIGN GUIDELINES FOR ELECTRICAL POWER SYSTEMS

5.1 General

5.1.1 The electrical power systems, at all voltage levels, are support systems for most of the items of plant equipment. A reliable electrical power supply is critical for maintaining control during normal operation, anticipated deviations from normal operation, as well as to power, control and monitor relevant plant safety functions in DBA and DEC.

5.1.2 The design should specify the required functions and performance characteristics of each electrical power system that provides normal, standby, emergency and DEC power supplies to ensure:

a) Sufficient capacity to support the safety functions of the connected loads in operational states, DBAs and DECs

b) Availability and reliability are commensurate with the safety significance of the connected loads

5.1.3 During shutdown, parts of the electrical power systems of the NPP may be out of service for testing or maintenance. The challenges to the robustness, reliability and availability of the electrical power system when the plant is shut down may differ from those that have to be addressed during power operation.

5.1.4 Electric power systems important to safety should be designed to ensure the availability of power supplies to equipment and systems that are essential to:

a) Shutdown the reactor and monitor the critical parameters of the reactor and important systems;

b) Maintain the reactor in safe shutdown state;

c) Safe handling of irradiated fuel/assemblies from core

d) Containment isolation;

e) Reactor core cooling; and

f) Spent fuel pool cooling

g) Prevent significant release of radioactive material to the environment under DBA and DEC.

During the conditions mentioned above, voltage and frequency variations for electric power systems important to safety should be within the capability of equipment connected to electric power systems important to safety.

5.1.5 The electrical power systems of NPP should meet all functional requirements under the steady state conditions, short term operation conditions and transient conditions defined in the design basis.

5.1.6 Electrical and internal events can cause symmetrical and asymmetrical perturbations in the plant. These events can be initiated:

a) In the transmission system, with the plant connected or not connected to the grid or shut down, or as a consequence of the plant separating from the grid owing to anticipated series/ shunt faults or voltage variations and frequency variations beyond an acceptable level;

b) By the tripping of the main generator, leaving the on-site power systems connected to the off-site power systems or to other on-site power systems;

c) In the on-site power systems, as a result of an electrical event such as a motor starting, a phase to ground fault or switching surges or Anticipated Series/Shunt faults.

d) starting/reacceleration of the load during supply changeover

5.1.7 The impact of such events (section 5.1.6) on all the on-site electrical power systems (AC and DC) should be evaluated, and it should be confirmed by specific analysis that the requirements for the allowable voltage and frequency are met and the protection system is adequate.

5.1.8 The analyses of system stability for grid transients should demonstrate that the plant could ride through and could remain connected to the grid for perturbations that do not result in the generator losing synchronization with the transmission system. These analyses should be done for fault clearance times as specified in Indian Electricity Grid Standards.

5.1.9 Electrical power systems should be designed to minimize risks to personnel and to minimize damage to equipment due to high temperatures, arc flash or mechanical stress caused by rated current, overcurrent or any internal mechanical stresses on the equipment.

5.1.10 Quality Assurance during design of Electric Power Systems should be as per requirements specified in AERB Safety code on Quality Assurance in Nuclear Power Plants AERB/NPP/SC/QA (Rev.1).

5.2 Design for Reliability

In the design of electrical power systems important to safety, design features such as redundancy, diversity, tolerance of random failure, independence of equipment and systems, tolerance of common cause failures, testability and maintainability, fail safe design, and selection of high quality equipment are typically used to provide the specified reliability of safety functions.

Redundancy

5.2.1 Electrical power systems important to safety should be redundant to the degree necessary to meet design basis reliability requirements.

5.2.2 EEPS should be divided into two or more independent and redundant groups. The redundancy should be consistent with that of the safety systems served. Each group should have the capacity and capability necessary to permit the systems it serves to fulfil their safety functions.

5.2.3 The level of redundancy should also take into account any increased unavailability of standby electric power systems due to maintenance and testing. For this, in addition to redundancy, wherever appropriate, diversity of structures, systems and components may be maintained while designing EEPS.

Independence

5.2.4 Independence is provided to prevent a failure, or an internal/external hazard from affecting redundant elements of safety systems. It also prevents a failure or hazard from affecting systems that provide different levels of defence-in-depth. Failure processes to be considered include:

a. Failures resulting from Design Basis Events (DBEs);

b. Exposure to the internal or external hazards;

c. Failure of common support systems;

d. Electrical connections between systems or divisions;

e. Data exchange between systems or divisions;

f. Common errors in design, manufacture, operations or maintenance.

5.2.5 Safety items should be such that they are not affected by the accidents to which they need to respond.

5.2.6 Safety systems should be independent from systems of lower safety classification as necessary to ensure that the safety systems can perform their safety functions during and following any event that requires these functions to be performed.

5.2.7 Redundant portions of safety divisions/ groups should be independent of one another to ensure that the safety division/ group will perform its safety functions during and following any event that requires these functions to be performed.

5.2.8 Failure of one part of the redundant electrical power structures, systems and components should not render other parts inoperable when they are required to function.

5.2.9 The functional failure of the support features of safety systems should not compromise the independence between redundant parts of safety systems or between safety systems and systems of lower safety classification. For example, assigning a safety system support feature such as room ventilation to the same division as the safety system it supports prevents the loss of mechanical function in one division causing a loss of electrical power system function in another division. Vital supporting systems should be designed to the same criteria as those for the safety-related loads and the power systems that they support

5.2.10 When isolation devices are used between systems of different safety importance, they should be a part of the system of higher importance. For example, non-safety systems (e.g. turbine lube oil pump and generator seal oil pump) that are supplied from the EEPS should be connected with safety grade isolation equipment. Such connections should not reduce the functional independence or system reliability of the EEPS below a level required for them to perform their safety functions.

5.2.11 The adequacy of design features provided to meet the requirements for independence should be justified.

5.2.12 Equipment and circuits that are required to be independent should be determined and delineated in the early phase of plant design and should be identified in documents and drawings in a distinctive manner.

5.2.13 Further guidance for meeting independence criteria is provided in the latest revision of IEEE 384.

Physical separation

5.2.14 Physical separation protects against common cause failure due to the effects of internal and external hazards. Internal hazards of concern include Water hazards from direct and indirect sources of water, such as spray, jet and seepage through roofs, walls, raceways and conduits; Fire; internally generated Missiles; Steam jets; Pipe whip; Chemical explosions; Flooding; Failure of adjacent equipment and heavy load drop. External hazards include seismic event, fire, flood, aircraft impact etc. Physical separation also reduces the likelihood of inadvertent errors during operation or maintenance on redundant equipment.

5.2.15 Physical separation is achieved by distance, barriers or a combination of the two. The safety guide on Fire Protection (AERB/SG/D-4) provides guidance on protection against fires.

Electrical isolation

5.2.16 Electrical isolation is used to prevent electrical failures in one system from affecting connected systems. Electrical isolation controls or prevents adverse interactions between equipment and components caused by factors such as electromagnetic interference, electrostatic pickup, short circuits, open circuits, grounding or application of the maximum credible voltage (AC or DC).

5.2.17 As far as practicable, non-safety loads should not be powered by EEPS. If it is necessary to power non-safety loads from EEPS, the non-safety loads should be isolated by means of safety classified isolation devices. An example of a preferred isolation device is a safety grade circuit breaker that is automatically tripped by an accident signal or downstream fault of non-safety loads or loss of voltage signal generated within of the same safety division as the isolation device.

5.2.18 Redundant divisions of EEPS should not be interconnected. Temporary connections between redundant divisions may be made during shutdown if a safety assessment confirms the following:

a) That the interconnections have interlocks that cannot be defeated by simple switch operation;

b) That the effects of these connections on the reliability of plant safety functions and on their vulnerability to common cause failure is acceptable.

These interconnections could also be used in station blackout conditions.

5.2.19 Examples of provisions for electrical isolation include circuit breakers, relays, electronic isolation devices, optical isolation devices, etc.

5.2.20 Qualification for electromagnetic compatibility complements electrical isolation by protecting against electromagnetic interference and electrostatic pickup.

5.2.21 When adequate separation and isolation from electrical faults between a safety circuit and a circuit of a lower class function is not provided, the lower class circuit (associated circuit) should be:

a) Analysed or tested to demonstrate that the association does not unacceptably degrade the safety class circuits with which it is associated;

b) Identified as part of the safety division with which it is associated.

c) Electrically separated from other components in the same manner as the circuits of the safety division with which it is associated.

Diversity

5.2.22 EEPS should be supplied from the following diverse electrical power supplies. Diversity in power sources is usually inherent in the architectural design of the power system. Typically, emergency electric power system loads can be supplied from:

a) Off-site power system, via the preferred power supply

b) Main generator, which is the preferred power source, or which will supply power during house load operation

c) Standby AC power source, which will supply the EEPS on loss of off-site power

d) DEC power supplies in station blackout conditions.

5.2.23 DC loads can be supplied from batteries or (via rectifiers) from any of the above mentioned sources.

5.2.24 Uninterruptible AC power systems can be supplied from batteries or battery chargers (via inverters) or from EEPS buses using bypass switches.

5.2.25 Where the design basis requires diversity for software based devices of an electrical power system, the guidance of AERB/SG/D-25 should be followed.

5.2.26 Diversity of power supply sources for specific loads, for example instrumentation and control systems, might often improve the availability of the overall system. This may be achieved by the use of diverse power sources or by supply from uninterruptible power supplies.

5.2.27 If non-electrical power systems are provided as a diverse means of accomplishing a given safety function, their associated power supplies and instrumentation and control systems should be independent of the system together with which they are intended to be diverse. This recommendation applies to multiple non-electrical power systems that are diverse as well as non-electrical power systems (such as steam or engine driven pumps) that are provided for diversity from electrical power systems.

5.2.28 In addition to physical separation and electrical isolation, diversity might be necessary to increase independence between redundant systems or between systems supporting different levels of defence-in-depth.

Common cause failures

5.2.29 The possibility of common cause failure, which could render EEPS unavailable to perform their safety functions when called upon, should be considered in the design, maintenance, testing and operation of the EEPS and their support systems.

5.2.30 The principles of diversity and independence (physical separation and functional isolation) should be used as appropriate to protect against credible common cause failure originating from the safety system equipment itself, in switching surges or voltage and/or frequency excursions from connected systems or from human involvement (e.g. operations and maintenance).

5.2.31 The principles of diversity and independence when appropriately followed help to ensure that primarily random equipment failure rather than identifiable common cause failure (fire, flood etc.) will be the primary cause of overall system unavailability. The possibility of other common cause failures, which may affect these principles should also be considered (e.g. poor fuel oil quality of Stand by AC power source).

5.2.32 If the nuclear power plant is connected to more than one transmission systems, one grid event alone may not influence emergency electric power system. If the redundant EEPS are fed from independent connections to the grid, the possibilities of common cause failure will also be reduced.

5.2.33 The primary protection features against common cause failures originating from the grid are:

a) Comprehensive design bases and guidelines that identify all possible events that could challenge the EEPS;

b) Verified capability of the EEPS to cope with these events, either by means of built-in features or by relay protection;

c) Verified capability not to transmit grid voltage excursions and frequency excursions to buses fed from rectifiers and inverters.

5.2.34 The primary protection features against CCFs for the standby power sources are:

a) Comprehensive design bases and guidelines that identify all possible events that could challenge the control, start and operation of the standby power sources

b) Verified capability of the standby power sources to cope with these events, either by built-in features or by relay protection (this also includes the transient performance during loading of the standby power sources)

c) Proper redundancy of control circuits and equipment to ensure reliability in starting and endurance in operation and to prevent unnecessary tripping.

Failure modes

5.2.35 Knowledge of component failure modes is necessary in order to apply the fail-safe concept. The failure modes of electrical components important to safety should be known and should be documented.

5.2.36 Failures of electrical components important to safety should be detectable by means of periodic testing or revealed by means of alarms or indications of anomalies.

5.2.37 The design should be such that failures are self-revealing except where such a design might result in an unsafe state or might cause a spurious actuation of a safety system.

Protection

5.2.38 The electrical protection scheme should prevent failures from disabling safety functions, to an acceptable level. Protective relays should be used for prompt removal from service of any element of a power system when unacceptable conditions occur, so as to prevent operating equipment degradation/ failure.

5.2.39 The protective actions of each load group should be independent of the protective actions provided by a redundant load group.

5.2.40 Selective tripping of circuit breakers should be used to minimize the impact of fault conditions. The protective devices should be properly sized, calibrated and coordinated so that only the faulty part of the electric power system is isolated without affecting the function of the healthy part. The speed of the protection scheme shall be as fast as possible so that the stability of the system is not affected and the damage to equipment is very minimum.

5.2.41 The protection scheme for the plant and the design of the plant's components should be such that disturbances in the preferred power supply do not jeopardize the required operation of EEPS and connected loads.

5.2.42 In an accident condition, equipment protection may be reduced to the essential set in order to give priority to the safety action.

5.2.43 The protection scheme should be capable of the following:

a) Operating the required devices upon detection of unacceptable conditions to reduce the severity and extent of disturbances of electrical power systems, equipment damage, and potential hazards to personnel and property.

b) Monitoring the connected preferred power supply with provisions to initiate, automatically or manually, transfer to an alternative supply.

c) Providing indication and identification of the protective operations.

d) Monitoring the availability of power for the protection systems' control.

e) Ensuring that only faulty equipment is disconnected from the power supplies.

5.2.44 The protection scheme should include consideration of reacceleration currents after voltage sags and interruptions or bus transfers.

Exposure to momentary increase in system fault current in excess of equipment rating is permitted during bus transfer when two power sources are momentarily connected in parallel.

5.2.45 The design of protective devices should include consideration of both symmetrical and asymmetrical faults of highest and lowest levels. Faults to be considered include all possible types of series and shunt faults, including events such as loss of a phase and ground faults in systems not connected to ground.

5.2.46 Provision of means to capture transients in events is desirable in order to support verification of the analysis performed and protection coordination.

5.2.47 Digital protective devices should be verified (including independent verification & validation for safety and safety related electrical system) for use in accordance with the safety function that they are intended to perform. For specific guidance AERB Safety guide on Computer Based Systems AERB/SG/D-25 and IEC-62671 should be referred.

5.2.48 The design of the protective devices for electrical power systems and for components of nuclear power plants should also comply with national standards that apply to the safety of electrical equipment and electrical installations, as well as with other relevant regulations on electrical equipment and electrical installations.

Confirmation of Reliability

5.2.49 Systematic assessments should be conducted to confirm that the reliability of EEPS commensurate with quantitative targets for reliability of the safety systems, which are supported by EEPS.

Application of Defence in Depth (DiD)

5.2.50 The NPPs rely on electrical power for various safety functions. The reliability of the power supplies are important for the safety of the plant. The electrical power systems are support systems necessary for all levels of Defence in Depth (DiD). It is essential that the NPP have a reliable power supply to control anticipated deviations from normal operation. It is also required to power, control and monitor the plant during all plant states. The following table provides the features of the electrical power systems that support the levels of DiD:

Level of DiD	Objective	Essential Means	Applied to EPS
1	Prevention of abnormal operation and failures	Conservative design and high quality in construction and operation	Comprehensive design basis, robust and reliable grid, robust and reliable on-site power systems
2	Control of abnormal operation and detection of failures	Control systems, limiting systems and protection systems and other surveillance features	Robust and reliable fault clearing system and coordination of protection, power supply transfer capability, house load operation possibilities
3	Control of accidents within the design basis	Engineered safety features and accident procedures	Robust and reliable safety power systems, robust and reliable on-site standby AC power supplies
4	Control of severe plant conditions, including prevention of accident progression and mitigation of the consequences of DECs	Complementary measures and accident management	Robust and reliable DEC power supply system
5	Mitigation of radiological consequences of significant radioactive release	Off-site emergency response	Not applicable

5.3 Electrical Equipment, Cables and Raceways

General

5.3.1 Electrical equipment should be selected, rated and qualified for its service conditions and environmental conditions.

5.3.2 Electrical equipment should be sufficiently fire retardant to prevent the propagation of fires. Guidance on aspects related to fire safety is provided in AERB/SG/D-4.

Rating and sizing

5.3.3 All items of equipment used in the electrical power systems in the plant should have a sufficient margin in operating parameters in comparison with their nominal rating.

5.3.4 Electrical equipment should be specified with an adequate design margin to ensure that future plant upgrades and modifications can be implemented without exceeding equipment ratings.

5.3.5 Analyses and simulations should be performed to confirm the design margins, on the basis of conservative assumptions and qualified methods.

5.3.6 Electrical loads connected to power system should withstand voltage and frequency variations with respect to rated conditions expected due to steady state, short term and transient conditions during operation of electrical power system.

5.3.7 The torque produced by motors connected to electrical power system should be adequate to enable satisfactory performance of associated driven equipment when subjected to, at their terminals, minimum voltage and maximum frequency as considered in the design bases for electrical power system. Further, no damage should be caused to connected equipment when required to operate at expected maximum voltage and minimum frequency.

5.3.8 Maximum input demanded by the motors due to conservative operating conditions expected for the driven equipment should be considered for design of electrical power system, associated feeders to motors and setting of protection relays for motor feeders.

5.3.9 The over load protection of components of electrical power system should be coordinated with the capability of components to carry without undue damage under such overloaded condition and without affecting other components/portions of electrical power system to which the over loaded components are also connected. Over loaded condition should be suitably annunciated in Main Control Room to draw attention of operator. The over load protection setting should be such that nuisance tripping of the component is also avoided during its entire permissible operating range.

5.3.10 While designing the electrical conductors consideration should be given to maximum environmental temperature, types of cable trays (i.e. ladder type/solid bottom type, with or without cover etc.), normal and fault currents, load factors, the arrangement of other cables in the same or nearby raceways and the influence of cable supports wall penetrations, floor penetrations, fire stop and fire retardant coating on cable heating.

Installation

5.3.11 Buses, raceways (i.e. trays or conduits) and their supports should be designed to withstand, with an appropriate margin, the mechanical loads imposed by the cables and their associated fittings. Redundant safety system buses, cubicles and cables should be adequately protected against the hazards that could result from postulated initiating events so that simultaneous failure of redundant safety systems, buses, cubicles and cables does not occur. Hazards that could affect buses, cubicles and cables include: the effects of fire, and the failure or malfunction of fluid systems and mechanical or structural components. Failure of mechanical equipment includes possible effects of pipe whip, jet impingement and the generation of missiles as a result of the failure of rotating equipment or other high energy systems. The installation shall conform to Central Electricity Authority (Technical Standards for Construction of Plants) regulations 2010 along with amendments.

Identification

5.3.12 Raceways and cables should be permanently identified with their respective divisions. Each cable, on installation, should be given adequate identification to ensure its installation in the proper raceway.

Cable splices

5.3.13 In general, the use of cable splices in raceways should be prohibited. Cable splices may be used for connections between field cables and equipment provided that the cable splices are qualified for the service. Qualified termination techniques may be necessary for safety cables and equipment in the containment to protect against high leakage currents that might be generated by exposure to environmental conditions caused by accident conditions.

Cable joints if required in long runs of cables should be provided in the outdoor areas only and not inside the main plant buildings

Cable separation

5.3.14 Physical separation by use of appropriate methods (e.g. distance or a physical barrier) should be provided between:

a) Cables classified as safety and non-safety;
b) Cables belonging to different safety divisions;
c) Cables of different voltage classes.

5.3.15 Cable separation should be as per IEEE-384 on Standard Criteria for Independence of Class 1E Equipment and Circuits.

5.4 Earthing

5.4.1 Earthing practices shall conform to the provisions of Central Electricity Authority (Measures relating to safety and Electric supply) regulations 2010 along with amendments, IS-3043 and/or IEEE-80, IEEE-81and IEEE-1050.

5.5 Lightning and Surge Protection

5.5.1 Provision should be made so that a lightning strike will not prevent the power systems and instrumentation and control systems from fulfilling their required safety functions and also provides protection to the personnel against high transferred potentials. The systems for achieving such a provision may rely on external or internal protection. Typically, a combination of both methods will be necessary.

5.5.2 External provisions will normally include either lightning conductors or a Faraday cage comprising the metal parts of the building that shield the building and its equipment from the effects of a lightning strike. Internal provisions could include specific electromagnetic shielding for rooms in order to create an environment protected from electromagnetic hazards.

5.5.3 Internal lightning protection will normally include shielding and surge arresters to protect against both the induced high voltage caused by the lightning current and high transferred voltage. High transferred voltages are caused by voltage differences between the ground and parts of the external lightning protection system and the associated grounding connections.

5.5.4 Structures that are not an inherent part of the plant, such as warehouses, offices and workshops for maintenance and support staff, should generally not be supplied from power distribution systems at the plant. If plant buses are used to supply power to ancillary buildings, adequate measures should be taken to ensure that electrical noise and voltage perturbations generated by equipment in these buildings do not adversely affect the plant power systems.

5.5.5 As far as possible, power systems for control and monitoring should not be distributed outside the plant. If it is necessary to distribute outside, adequate measures should be taken to minimize the risk for disturbances due to induction or other influences.

5.5.6 Connections to other buildings can be justified if the cable route is protected with adequate protection, such as grounded armour against induced voltages and rise in ground potential caused by lightning.

5.5.7 Switching operations, rectifiers, inverters and rotating equipment can generate harmonics and electrical noise that may be detrimental to equipment designed to operate at nominal frequency and voltage. Additional equipment to filter or suppress electrical noise may be necessary for the reliable operation of equipment sensitive to electrical noise in the power system.

5.5.8 Connections of lightning protection systems to ground should be routed so that the effects of lightning discharges do not jeopardize either the safety functions of safety power systems or the lightning protection grounding.

5.5.9 Lightning protection practices shall conform to the IEC 62305.

5.6 Equipment Qualification

5.6.1 Electrical power systems and components important to safety should be qualified for their intended function when necessary, and in the prevailing environmental conditions (DBA and DEC) over the design life of equipment.

5.6.2 The qualification should assure confidence commensurate with the safety classification of the system or component. Quality group classifications of equipment of the power system are reviewed and provided in line with AERB Code on 'Quality Assurance in Nuclear Power Plants', AERB/SC/QA (Rev-1).

5.6.3 Equipment qualification covers environmental qualification, qualification for internal and external hazards and electromagnetic qualification.

Equipment Qualification Program

5.6.4 The qualification programme(s) should address all topics affecting the suitability of the system or component for its intended functions important to safety, including:

a) Suitability and correctness of functions and performance;

b) Environmental qualification of components;

c) Seismic qualification of components;

d) Electromagnetic qualification.

5.6.5 IEEE-323 should be referred for further guidance on equipment qualification.

5.6.6 Qualification should be based on an appropriate combination of methods, including for example:

a) Use of engineering processes and manufacturing processes in compliance with recognized standards;

b) Demonstration of reliability;

c) Past experience in similar applications;

d) Type testing;

e) Testing of supplied equipment;

f) Analysis to extrapolate test results obtained or operating experience gained under pertinent conditions.

5.6.7 It is generally not necessary to apply all of the methods mentioned. The specific combination of methods will depend on the system or component under consideration. For example, the qualification of pre-existing items might place more emphasis on past experience and analysis to compensate for a lack of completely documented verification and validation in engineering and manufacturing. The method or combination of methods used for equipment qualification should be justified and documented.

5.6.8 Type testing of actual equipment performance by the manufacturer according to recognized standards using simulated service conditions, is a method of qualifying equipment. This method may be used for qualifying the greater portion of equipment in Electrical power systems and components important to safety. Where manufacturers' type tests are insufficient for NPP, additional tests should be performed to demonstrate that the equipment will perform as required in the specified environment.

5.6.9 Where operating experience is used to support equipment qualification, it should be shown to be relevant to the proposed use and to the environmental conditions of the target application and from mission time considerations for which equipment is designed to operate. Equipment that has operated successfully under comparable service conditions can be considered qualified for equal or less severe service. Operating experience can provide information on limits of extrapolation, failure modes and failure rates.

5.6.10 An analysis that is part of the evidence for equipment qualification should include a justification of the methods, theories and assumptions used. For example, the validity of the mathematical models used for equipment qualification may be justified on the basis of experimental data, test data or operating experience.

5.6.11 Traceability should be ensured between each installed system and component important to safety and the applicable evidence of qualification. This includes traceability not only to the component itself, but traceability between the qualified configuration and the installed configuration.

5.6.12 Equipment qualification programme should demonstrate that the design of electrical power structures, systems and components and software meet all requirements for capability, capacity and reliability important to safety contained in the applicable design bases and equipment specifications. Examples of reliability requirements include, for example, requirements for fail-safe behaviour, conformance with the single failure criterion, independence, failure detection, maintainability and service life.

5.6.13 Equipment qualification programme should demonstrate that the as-built electrical power systems and installed components correctly implement the qualified design.

Environmental qualification

5.6.14 Environmental conditions such as those resulting from high and low atmospheric temperatures, pressure, humidity, contact with chemicals, saline atmosphere, high wind, rain, lightning discharges, snow, and ice are considered in the review of the preferred power system to determine any effects on function

5.6.15 'Environmental qualification' means qualification for temperature, pressure, humidity, contact with chemicals, radiation exposure, meteorological conditions, submergence and ageing mechanisms as conditions that could affect the proper functioning of components.

5.6.16 Structures, systems and components important to safety should be designed to accommodate the effects of, and should be compatible with, the environmental conditions associated with all plant states in which they are required to function.

5.6.17 Components important to safety should be shown to meet all requirements for the design basis when subjected to the range of environmental conditions specified in the design basis.

Components exposed to mild environmental conditions

5.6.18 For equipment located in a mild environment (components whose environmental conditions in accident are at no time more severe than conditions in normal operations) for meeting its functional requirements during normal environmental conditions and anticipated operational occurrences, the requirements should be specified in the design/ purchase specifications. Environmental qualification of components of an electrical power system that are important to safety and located in mild environment may be based on supplier certification that the components are suitable for the specified operating conditions.

Components exposed to harsh environmental conditions

5.6.19 Environmental qualification of safety classified components of electrical power systems whose environmental service conditions in accident conditions are at any time significantly more severe than conditions during normal operation (i.e. harsh environmental conditions) should show that the component is, at the end of its qualified life, capable of performing its safety functions under the full range of specified service conditions. Showing that components can function as required at the end of their qualified life involves addressing significant ageing effects (e.g. radiation ageing and thermal ageing) to show that the required functionality is maintained at the end of the qualified life. Usually, this includes providing further conservatism, where appropriate, to allow for unanticipated ageing mechanisms.

5.6.20 In defining the equipment qualification programme, the worst credible combinations of environmental service conditions, including synergistic effects between service conditions, should be addressed.

5.6.21 If it is necessary to test separately for different environmental conditions (e.g. separate tests for radiation effects and for temperature effects), the sequence in which these tests are conducted should be justified as one that appropriately simulates the degradation caused by the combined environmental conditions.

5.6.22 The most rigorous environmental qualification methods may be applied only to safety components. Environmental qualification of safety components that are expected to operate in harsh environmental conditions should include type testing.

5.6.23 When protective barriers are provided to isolate equipment from possible environmental effects, the barriers themselves should be subject to a qualification programme to validate their adequacy.

Qualification for Internal and external hazards

5.6.24 The plant design basis and the plant's safety analysis will identify internal and external hazards that the plant is required to withstand for operation or is required to withstand safely, and for which protection or system qualification is necessary.

5.6.25 Electrical power systems and components should be protected against the effects of fire and explosion in accordance with the recommendations of AERB/SG/D-4. Electrical power systems and components should be protected against the effects of other internal hazards in accordance with AERB/SG/D-3.

5.6.26 Electrical power systems and components should be designed and qualified to withstand seismic hazards in accordance with the recommendations of AERB/SG/D-23. Equipment used in EEPS should be capable of fulfilling its performance requirements, if required, during and after an extreme external event. Electrical power systems and components should also be protected against or designed and qualified to withstand other external hazards in accordance with the recommendations of AERB/SG/S-3 for 'Extreme Values of Meteorological Parameters'.

Electromagnetic qualification

5.6.27 Equipment and systems important to safety, including associated cables, should be designed and installed to withstand the electromagnetic conditions in the environments in which they are located or that might get generated during transient conditions.

5.6.28 Detailed requirements for electromagnetic compatibility should be determined for all electrical power systems and components, and the compliance of these systems and components with the requirements should be demonstrated. Appropriate practices for installation and maintenance should ensure the proper implementation and continued effectiveness of these provisions. As a minimum, equipment should have electromagnetic compatibility levels as stipulated in respective industrial standards.

5.6.29 Electromagnetic qualification of electrical power systems and components depends upon:

a) A combination of system design and component design to minimize the coupling of electromagnetic noise to electrical components;

b) Testing to demonstrate that components can withstand the expected levels of electromagnetic noise;

c) Testing to demonstrate that electromagnetic emissions are within tolerable levels.

5.6.30 The types of electromagnetic interference that should be considered in the design of electrical power systems and components include:

a) Emission of and immunity to radiated electromagnetic disturbances;

b) Emission and conduction of electromagnetic disturbances via cables;

c) Electrostatic discharge;

d) Switching transients and surges;

e) The emission characteristics of wireless systems and devices used at the plant as well as those of repair, maintenance and measuring devices. Wireless systems and devices include, for example, mobile phones, radio transceivers and wireless data communication networks.

5.6.31 Radiated and conducted electromagnetic emission and immunity levels for different equipment should be as specified in the applicable standards.

5.6.32 Equipment and systems, including associated cables, should be designed and installed so as to appropriately limit the propagation (both by radiation and by conduction) of electromagnetic interference among items of plant equipment. Instrumentation cables should have twisting and shielding sufficient to minimize electromagnetic interference and electrostatic interference.

5.6.33 AERB/NPP-PHWR/SG/D-20 provides additional recommendations and guidance for the electromagnetic compatibility of the electronic elements of the electrical power system.

5.6.34 Techniques for minimizing the production and coupling of electromagnetic noise include:

a) Suppression of electromagnetic noise at the source;

b) Separation and isolation of signal cables for instrumentation and control systems from power cables;

c) Shielding of equipment and cables from external magnetic and electromagnetic fields sources;

d) Filtering electromagnetic noise before it can become coupled to sensitive electronic circuits;

e) Neutralization or isolation of electronic equipment from ground potential differences;

f) Proper grounding of electrical equipment, raceways, cabinets, components and cable shields.

g) Optical transmission of signals when feasible

5.6.35 In case the equipment does not qualify for the EMI/EMC requirements as per respective industrial standards, it should be considered whether it is necessary to establish exclusion zones in the vicinity of certain sensitive equipment within which the operation of wireless devices and other portable sources for electromagnetic interference (e.g. welders) is not permitted.

5.7 Design to cope with Ageing

5.7.1 It should be ensured that ageing effects will not impair the ability of safety components to function under severe environmental conditions. Such degradation could occur well before the functional capabilities under normal conditions are noticeably affected.

5.7.2 Ageing mechanisms that could significantly affect electrical components, and means for following the effects of such mechanisms, should be identified in the design process. Ageing effects are most commonly due to heat and to radiation exposure, but other phenomena (e.g. mechanical vibration or chemical degradation) could be important ageing mechanisms for certain components.

5.7.3 Maintenance programme, surveillance programme and ageing management programme should include activities to identify any trend towards degradation (ageing) that could cause equipment to become incapable of performing its safety function. Examples of monitoring techniques are:

a) Testing of plant components or testing of components subject to ageing that is representative of that of plant components;

b) Visual inspections;

c) Analysis of operating experience.

5.7.4 Means to address ageing impacts include:

a) Component replacement before the end of its qualified life;

b) Adjustment of functional characteristics to account for ageing effects after due analysis that such adjustment will fulfil the safety function of the component/ equipment even at the end of its design life;

c) Changes to maintenance procedures or environmental conditions that have the effect of slowing the ageing process.

5.7.5 The qualified life of safety components that have to perform their safety function in harsh environmental conditions should be determined. Safety classified components should be replaced before the end of their qualified life.

5.7.6 Provisions may be made to monitor critical parameters like winding temperature, ambient temperature, insulation dielectric properties (insulation resistance, polarization index, capacitance and tan delta), current and loading cycles and records to be maintained for various electrical equipment and cables for assessment of their life due to ageing. Dummy cables may also be laid in such areas to enable collection of samples for determining the residual life remaining due to the effects of radiation, high temperature and humidity. Refer Safety Guide on Life Cycle Management (AERB/SG/O-14).

5.8 Control of Access

5.8.1 Access to equipment in systems important to safety should be limited so as to prevent unauthorized access and to reduce the possibility of error.

Effective methods include appropriate combinations of physical security, for example locked enclosures, locked rooms, alarms on enclosure doors and administrative measures.

5.8.2 AERB/SG/D-25 provides additional recommendations on access control and on the security of computer based applications used in electrical power systems.

5.9 Surveillance Testing and Testability

5.9.1 All systems important to safety should include provisions for testing, including built-in test capabilities where appropriate. Design of the test provisions should be coordinated with the design of the operational test programme so that availability requirements of systems and components can be fulfilled. Testing and calibration of safety system equipment should be feasible in all modes of normal operation[5], including power operation, while retaining the capability of safety systems to fulfil their safety functions.

5.9.2 The test programme for electronic components of electrical power systems, including protective

[5] Normal operation includes plant states of start-up, normal operation and shut-down

devices that include electronic components, should also meet applicable parts of guidance in AERB/SG/D-25.

5.10 Maintainability

5.10.1 The design of electrical power systems should include maintenance plans for all systems and components.

5.10.2 Electrical power systems important to safety should be designed and located to make surveillance and maintenance simple, to permit timely and safe access and, in the case of failure or error, to allow easy diagnosis and repair and to minimize risks to maintenance personnel.

5.11 Testing and Maintenance

5.11.1 Provisions should be made for positive Isolation of electrical equipment while removing from service for testing or maintenance in order to protect personnel and to avoid spurious operation.

5.11.2 Unavailability or bypass of safety system components should be indicated in the control room.

5.12 Sharing of Structures, Systems and Components in Multi-Unit Plants

5.12.1 Each unit in a multi-unit power plant should have separate and independent power systems important to safety.

5.12.2 At a multi-unit station, off-site power supply sources and switchyard may be shared between multi-units. Shared circuits should simultaneously supply all loads required for each design mode of operation of multi-units. Status indication of shared circuit breakers should be available in the main control room of each of the units, which share these facilities.

5.12.3 Where off-site power supplies are shared between multiple units at a multi-unit plant, the ability to disconnect a unit should not affect the availability of the off-site supply to any other units.

5.13 Marking and Identification

5.13.1 Safety system equipment (including cables and raceways) should be readily identifiable in the plant for each redundant element of a safety system.

5.13.2 Consistent and coherent method of naming and identifying all electric power components should be used throughout the design, construction and operation stages of the plant. Such identification should not require frequent reference to drawings, manuals or other material.

5.13.3 The components of different safety divisions should be readily distinguishable from each other and from components of lower safety classification. Identification may be in the form of tagging or colour coding.

5.14 Containment Electrical Penetrations

5.14.1 Electrical penetration assemblies should be provided in reactor containment structures for conductors of circuits of electric power supply systems. These electrical penetrations should be rated and qualified for expected service and environmental conditions that include cumulative radiation effects expected throughout their design life and accident conditions.

Safety Classification

5.14.2 Electrical penetrations are elements of accomplishing the safety function of the containment and should always be safety classified.

5.14.3 Structural integrity functions include the ability to withstand rated currents and fault currents without the penetration leak rate exceeding the levels specified in requirements. The safety classification of a penetration’s electrical functions that do not affect structural integrity will follow the safety classification of the in-containment items that depend on the penetration.

Rating

5.14.4 Containment penetrations should be rated:

a) For continuous service at a voltage that is greater than or equal to the voltage of the systems of which the conductors are part;

b) For power frequency and impulse voltage withstand capability as applicable greater than or equal to that specified transient voltage for associated cable.

c) To carry the current taking into account the voltage variations and short circuits as well as demands from loads under all plant states, without exceeding allowable conductor temperatures or degradation of pressure boundaries of the assemblies.

d) To carry short circuits safely over the period of time required for the protective device to clear fault currents, with account taken of credible voltage variations;

e) To withstand, without loss of mechanical integrity, the maximum possible overcurrent condition that could occur following a single random failure of a device protecting against circuit overload.

Protection

5.14.5 The continuous current ratings and capabilities of the electrical penetrations should be considered in the settings of the protective devices. A containment penetration that can indefinitely withstand the maximum current available due to a fault inside the containment does not need redundant protection.

Separation

5.14.6 The penetrations should meet the same separation criteria as the cables to which they are connected. For e.g. Separate penetration assemblies should be provided for each group, and they should meet independence criteria as the cables to which they are connected.

5.14.7 Electrical penetration assemblies should meet the requirements of IEEE-317.

5.15 Distribution Systems

Capability

5.15.1 Each distribution system should have sufficient capacity and capability:

a) To supply the required loads under all required operating conditions;

b) To withstand the maximum credible overcurrent under electrical fault conditions;

c) To withstand transient conditions without damage to, or adverse effects on, any of its components;

d) To withstand power supplies and loads as demanded.

Protection

5.15.2 All main circuits and branch circuits should be protected against overloads and short circuits, and should be supervised for ground faults and protected where applicable.

5.15.3 Protective devices should be properly sized, set and coordinated to protect equipment, buses and cables of the main circuits and branch circuits from damage in overload conditions and fault conditions. The protective devices for safety systems should be part of the safety system.

5.16 Controls and Monitoring

5.16.1 Sufficient instrumentation and control equipment should be provided in the Main Control Room (MCR) to monitor and control on-site and off-site power systems. The human–machine interface for electrical power systems should be as per the guidance of AERB/SG/D-20. Design should also provide appropriate monitoring and control at local control panels/points as per AERB/SG/D-20.

5.16.2 Sufficient instrumentation and control equipment which is physically and electrically separate from MCR should be provided in the Supplementary Control Room (SCR)/supplementary local control points to monitor and control the EEPS necessary for performance of the safety functions that are assigned to that location. Monitoring of DEC power supplies will be performed locally near DEC power supplies.

5.16.3 Controls of EEPS should be automatic and/or manual depending on the requirement. Manual control should only be accepted if it meets the requirements specified in the AERB safety codes for design of NPPs.

5.16.4 Alarms warning about the loss of the operational status of the safety power supplies should preferably be actuated by de-energized logic.

5.17 Fire Protection

5.17.1 The design of EEPS should take into account the guidance provided in design safety guide on Fire Protection (AERB/SG/D-4).

5.18 Lighting

5.18.1 Areas having equipment belonging to one group of EEPS should be provided with emergency lighting from the same group. Critical operating areas like control room, etc. should have emergency lighting system from two groups. Part of this emergency lighting should be powered from class II or I source. In addition, portable lighting having in-built energy source should be provided in the control room.

5.18.2 Lighting system and illumination levels shall be as per IS-3646 "Code of Practice for Interior Illumination”.

5.19 Station Blackout

5.19.1 Operational experience has shown that loss of the preferred power supply concurrent with a generator trip and unavailability of all standby AC power supplies is a credible event. Such an event may affect a single unit, and even all units on one site. Such an event is called station blackout and its frequency of occurrence should be low enough to be considered and analyzed as a Design Extension Condition (DEC) event.

5.19.2 The term does not include the simultaneous failure of an uninterruptible AC power system or DC power sources, or the failure of DEC power sources that are diverse in design and not susceptible to the events that caused the loss of on-site and off-site power sources. IAEA TECDOC-1770 provides general guidelines on design provisions for withstanding SBO conditions at NPPs. The SBO probability and the duration of station blackout depend on various factors as below:

a) Factors influencing total failure of Class-IV power supply are:

- Plant grid interactions;
- Grid disturbances leading to cascade tripping of transmission lines;
- Non-availability of standby transformer when unit is not in service (applied to units, where generator circuit breakers are not provided);
- Switchyard faults and/or faults in Class-IV power supply system;
- Weather induced disturbances;
- Other external events such as earthquake, tsunami, etc.

b) Factors influencing total failure of Class III power supply are:

- Number of standby AC power sources provided for each unit and the number of Stand by AC power sources required to meet safety loads of the unit;
- Reliability of Stand by AC power sources to start on demand and accept loads;
- Degree of independence between redundant Stand by AC power sources provided;

- Expected frequency of loss of Class IV power supply;
- Faults in Class III power system.

5.19.3 SBO duration depends on the factors, which have caused it and the station capability to restore power supply either through any of the normal sources or alternate power sources. SBO duration depends on the following:

a) Number of voltage levels at which the station is connected to the grid (e.g. 220 kV only, 400 kV only or both 400 kV and 220 kV);

b) Availability and degree of control on alternate power sources;

c) Availability of direct transmission lines to near-by hydro and gas turbine generating stations;

d) Availability of laid down procedures, trained personnel and communication facilities to restore power supplies;

e) Inter unit ties;

f) Probable time to restore Class IV;

g) Meantime to repair failed Stand by AC power sources.

Considering the above factors the expected SBO duration is arrived for each station.

5.19.4 The plant's capability to maintain safety functions and to remove decay heat from spent fuel should be analyzed for the period for which the plant is in SBO condition. Adequate provisions should be included in the design to prevent any significant fuel damage for the period during which the plant is in SBO condition.

5.19.5 Considering the expected SBO duration, safety analysis should be performed for the plant, to check the adequacy of the design. If required, additional provisions should have to be made to ensure safety of the plant during the expected SBO duration.

5.19.6 Several design measures are possible as a means of increasing the capability to cope with a SBO condition. These measures include, for example:

a) increasing the capacity of batteries to supply power to safety instrumentation and control equipment, and to other vital equipment;

b) use of unit to unit connections;

c) installing a DEC power source that is diverse in design and is protected from hazards that could degrade the preferred power sources and standby AC power sources.

5.19.7 Among various measures to mitigate the consequences of SBO is the provision of fire water addition to Steam Generators in PHWR based NPP. Diesel driven Fire water pumps can be used as one of the diverse safety measures during SBO to provide necessary water supply to steam generators to remove decay heat from the reactor coolant system. The surveillance testing of fire water pumps required to be operated during SBO conditions should be carried out for the duration of minimum 8 hours periodically.

Prolonged SBO

5.19.8 In a situation where it may not be possible to recover the offsite or standby AC power sources within the expected coping duration for a SBO event, the plant enters the Prolonged SBO condition which can last from several hours to several days. Means should be provided to cope with a prolonged SBO by DEC power sources like stationary/ portable (battery charger/rectifier, instrumentation and controls supplies, etc.) spot power and mobile generators (for larger electricity demands) for enhancing electrical supplies. The details are covered in chapter 8 and 9 of the safety guide.

5.19.9 Each site should also establish the minimum coping capabilities consistent with unit specific evaluation of the potential impacts and responses to prolonged SBO. In general, this coping can be thought of as occurring in three phases:

- Phase 1: Use of installed equipment such as steam/diesel-driven pumps or battery powered systems, typically during the first 8 hours after the initiation of the incident.
- Phase 2: Augment or transition from installed equipment to on-site, dedicated, permanently installed or mobile equipment and consumables to maintain or restore key functions, typically up to 7 days from the initiation of the incident.
- Phase 3: Obtain off-site support until the normalcy is restored.

6. DESIGN GUIDELINES FOR PREFERRED POWER SUPPLIES

6.1 General

6.1.1 The transmission system should be able to supply the NPP with power during startup, shutdown and emergencies in a stable and continuous manner. The transmission system should also be able to dispatch the energy from the NPP in a stable and continuous manner even under anticipated grid events when the plant remains connected to the grid.

6.1.2 The preferred power supply to the EEPS is the supply from the grid or main generator. During normal start-up or during normal operation of the unit, the station auxiliary loads can be supplied either totally by the Unit Auxiliary Transformer (UAT) or totally by standby transformer (ST) of any unit or partly by UAT and partly by ST. During shutdown of the unit, the station auxiliary loads can be supplied through ST of any unit or through generator transformer (GT) and UAT either by opening generator circuit breaker (if provided) or by disconnecting the appropriate bus duct links between GT and generator. The generator can power the on-site power systems during house load operation.

6.1.3 The preferred power supply to NPP should be designed in such a way that outage of one UAT or one ST does not affect the normal operation of the NPP. The quantities and capacities of these transformers should be designed accordingly.

6.1.4 The preferred power supply could also come from a separate connection to the grid. In order to minimize the risk for common cause failure caused by events on the grid, the switchyard or the main generator, feasibility of connecting different divisions of the electrical power systems of the NPP to different preferred power supplies without a significantly increased risk of undue trips and other disturbances could be considered.

6.1.5 Two or more circuits from the preferred power supply sources to emergency electric power system shall be provided.

6.1.6 Each circuit of preferred power supply connections to EEPS should be designed to provide sufficient capacity and capability to power the equipment connected to that circuit, which are important for safety during normal operation and Design Basis Events.

6.1.7 The preferred power supply and EEPS should be connected through safety related isolating device (e.g. circuit breaker) located within the boundaries of EEPS.

6.2 Off-Site Power Supplies

6.2.1 Off-site power shall be supplied by minimum two physically independent transmission line connections that are so designed and located to minimize, to the extent practicable, the likelihood of their simultaneous failure. These connections from the grid to the plant provide power supply to the preferred power supply system. Distribution system should be designed to minimize the simultaneous loss of two transmission connections as a result of failure of transmission equipment (like a transmission tower, a single breaker, a switchyard bus, a switchgear bus or a cable). These transmission lines need not necessarily be routed through separate rights of way.

6.2.2 In specific reactor designs, where AC power supply is not required for mitigating the consequences of DBA, requirement of number of transmission line connections to the plant should be based on safety analysis of the plant.

6.2.3 As a minimum, each off-site power supply should have the capacity and capability to power all electrical loads required to mitigate the consequences of all design basis accidents and anticipated operational occurrences.

6.2.4 Each off-site supply required for normal plant operation, startup and shutdown should have the additional capability to power all the normal electrical loads of the other co-located units.

6.2.5 A common gantry/take-off structure provided for terminating multiple off-site transmission lines is acceptable if there are more than two off-site connections to the switchyard.

6.2.6 The electrical protective system should be provided such that fault in one off-site circuit is cleared at the earliest to minimize the probability of loss of any other off-site circuit.

6.3 Availability

6.3.1 In the event of loss of one of the power supply sources to Class-IV buses, an automatic bus transfer system should be provided to restore power to the affected bus from the other supply source.

6.3.2 The transfer system for the auxiliary/house loads should be evaluated against the safety requirements for the design. The transfer to the second circuit, both manually and automatically, should be easy to accomplish. Variations in voltage and in-rush currents during the transfer should be considered in the design of the transfer sequence.

6.3.3 Feasibility of plant operation at house load should be established during design and if feasible, should be demonstrated during commissioning.

6.3.4 NPP should in consultation with the electric grid operator study feasibility of providing a suitable islanding scheme for the NPP. As a part of this, protection settings should be developed. This should be based on load flow, short circuit and stability studies. While developing the scheme, availability of radial transmission loads with adequate capacity to take care of generation at NPPs should be considered. If single radial load is not available then NPP itself or with one or more generating stations may be included in the islanding scheme to a portion of the grid. In addition, proper care should be taken to limit the portion of grid to be involved in the scheme by taking the reliability of isolations required for successful islanding mode of operation. Based on the study, if suitable islanding scheme can be developed, it should be implemented as this enhances further the availability of offsite power to NPP during certain grid disturbances

6.3.5 During islanding mode or house load operation, the on-site power system should be designed to accommodate the variations and transients of voltage and frequency from the generator when transferring from normal source of supply to islanding or house load operation.

6.3.6 Feasibility of supplying off-site power to Class IV buses through generator transformer and unit auxiliary transformer either by opening generator circuit breaker (if provided) or by appropriate disconnection of bus duct links, may be considered in design. The same, if applicable, should be established before regular operation of NPP. This will help in establishing availability of another source of class-IV power supply.

6.3.7 There may be alternate on-site or off-site power sources (e.g. hydro/gas based station) that can be used to increase the availability of power supply to emergency electric power system buses but which are not part of these systems

6.3.8 At a multi-reactor site, an important feature in this context is the ability to feed power to emergency electric power system of any unit from the plant generators of other units independent of the state of transmission lines to the electrical grid. Such alternate power sources should be considered while designing the EEPS. The reliance placed on them whether they are connected, automatically or manually, will depend on many factors such as the availability of the alternate source, the nature of their design and in particular, the degree of administrative control the plant operators can exercise over their operation.

6.4 Switchyard

6.4.1 The physical design of the switchyard should be such as to minimize the possibility of a single equipment failure causing the failure of off-site circuits that are credited with supplying safety loads.

6.4.2 Switchyard should have a minimum of two buses. Switchyard should be designed as per Indian

Standards and Code of Practices.

6.4.3 Switchyard equipment should be designed to withstand the stresses of worst case faults. Protective systems should minimize the probability of failure of all off-site circuits that are credited with supplying safety loads.

6.4.4 As far as practicable, control circuits to outdoor switchyards should be equipped with overvoltage protection where they enter the plant, and the switchyard control circuits should be isolated from the control circuits inside the plant.

6.5 Grid Stability and Reliability

6.5.1 The electrical grid should provide stable off-site power, i.e. it should be capable of withstanding load variations without exceeding the specified voltage limits and frequency limits as considered in plant safety analysis and the national grid code.

6.5.2 Load flow studies should be performed during the design stage and subsequently whenever major changes have taken place in the sources connected to or transmission network of the grid to ensure that at least one of the off-site connections to the switchyard is available even under the following conditions:

a) loss of generating unit of NPP;

b) loss of largest generating unit of the grid;

c) loss of largest transmission line or inter-tie;

d) loss of largest load in the grid;

e) loss of a transmission line of NPP switchyard;

f) Loss of the double circuit from NPP switchyard

g) Maximum fault level at the Generating Switchyard.

6.6 Interface between NPP and Grid

6.6.1 The NPP requires particular coordination between the transmission system operator and the NPP operating organization for the purpose of ensuring safe plant operation and safe shutdown. This cooperation is based on the common goals of ensuring nuclear safety and ensuring the security of supply of the electrical power system.

6.6.2 The NPP operating organization and the transmission system operator should determine and establish requirements for equipment interfaces and communication interfaces.

7. DESIGN GUIDELINES FOR EMERGENCY ELECTRIC POWER SYSTEMS

7.1 General

The plant electrical power system shall be designed and constructed in accordance with national and international standards and national safety codes to ensure a high level of reliability and availability in all modes of plant operation.

7.1.1 The equipment of Emergency Electric Power System are required to provide electric power supply to equipment and systems performing the safety functions under various DBEs. Emergency Power System shall be independent of preferred power supply system so that no single event would result in simultaneous failure of both the systems. Preferred power supplies and Emergency power supplies shall have capacity and capability to independently meet the plant electrical loads under all plant states.

7.1.2 This puts stringent requirements in the selection, design, qualification, operation and maintenance of EEPS. Equipment of EEPS shall be capable of performing its intended function during and subsequent to specified design basis earthquake conditions.

7.1.3 Variations in voltage and frequency of the electrical power system of the NPP in any mode of plant operation should not degrade the performance of any safety system equipment.

7.1.4 Equipment of EEPS shall have provision to extend power supply from DEC power source to essential equipment for performance of safety functions and for monitoring of essential plant parameters during a prolonged SBO of up to 7 days duration.

7.1.5 Specific portion of the EEPS that is used for supplying power from DEC power source during DEC shall be capable of fulfilling its performance requirements during and after extreme seismic event.

Anticipated electrical events

7.1.6 Systematic approach should be taken to identify the variations and transients in voltage and frequency on the safety classified buses that could result from events on the preferred power supply or events in any of the on-site electrical power systems, and to confirm the adequacy of the protection scheme. Examples of anticipated electrical events to be considered are given in Section 5.1.6.

7.1.7 Standby AC power sources used for on-site power systems will have variations in voltage and frequency during load sequencing. The magnitude of these variations in voltage and frequency should not affect equipment that is being started, already sequenced or operating.

7.1.8 An event could challenge different components in the electrical power systems, depending on rise time, fault time, amplitude or asymmetry. All modes of operation and both symmetrical and asymmetrical events should be considered in the analyses.

Monitoring and switching of buses

7.1.9 Degradation of the preferred power supply of each EEPS bus should be detected on the buses of EEPS.

7.1.10 Buses affected by degradation of the preferred power supply should be alarmed and automatically disconnected from their power source if the degradation exceeds the levels specified in the design requirements. Simultaneously signal should be generated to shed loads of the EEPS bus and start alternative power supply source for that particular EEPS bus.

7.1.11 After a bus is disconnected from a preferred power supply that has been degraded, after ensuring healthiness of the bus, it should automatically be connected directly to alternative sources in the following order:

a) Available preferred power supply

b) The standby power source for that division of EEPS.

7.1.12 A time delay may be associated with the disconnection to allow the system to ride through minor disturbances. The time delay should be commensurate with the assumptions made in the accident analysis.

7.1.13 One circuit breaker each should be provided at output from preferred supply end and another at receiving end of the EEPS bus.

7.1.14 The parameters of the EEPS including the availabilities claimed in the design analysis that are relevant to the safe operation of the plant in operational states and under design basis accident conditions should be identified and used in the establishment of operational limits and conditions for the plant.

7.1.15 Each division should have an independent scheme for detection and protection to disconnect the EEPS buses from the preferred power supply, to shed loads from the EEPS buses and to start the standby AC power sources in the event of degradation in voltage, degradation in frequency or loss of voltage.

7.1.16 Degradation in voltage or frequency should be alarmed in the Main Control Room (MCR). Each scheme should monitor all three phases. Measuring circuits should be immune to harmonics.

7.1.17 Failures in the measuring circuits should not cause incorrect operation or prevent correct operation of protection scheme.

7.1.18 The design should minimize unwanted disconnection of the preferred power supply. The use of coincident logic and time delays to override transient conditions is a way to minimize unwanted disconnection.

7.1.19 Testing and calibration of safety system equipment should be possible during all modes of normal operation including power operation while retaining the capability of the safety systems to fulfil their safety functions. However, the capability for testing and calibration during power operation is not necessary if it were to affect adversely the safety or the operation of the plant.

7.1.20 The under-voltage and time delay set points for degraded voltage protection should be determined on the basis of an analysis of the voltage requirements of the safety loads at all on-site distribution system levels.

7.1.21 For protection against external event i.e. flooding, equipment associated with EEPS should be located at an elevation above Design Basis Flood Level (DBFL). However, if EEPS or a portion of EEPS is required to remain functional to transfer power from DEC power supplies to loads required for mitigating consequences of DEC, such portions of EEPS should be protected from Beyond Design Basis Flood Level (BDFL) and suitable electrical isolation provided with those portions of EEPS designed for DBFL. DBFL and BDFL are established as per the relevant AERB safety guide.

7.2 Design for Reliability

Single failure criterion

7.2.1 While the single failure criterion is normally applied only to safety systems, the concept of single failure criterion shall be applied to EEPS for ensuring high functional reliability. The concepts such as redundancy, independence, testability, continuous monitoring, environmental qualification and maintainability shall be used to achieve compliance with the single failure criterion.

Completion of protective action

7.2.2 The emergency electrical power systems and their protective devices and automatic features should be designed so that, once initiated automatically or manually, the intended sequence of protective actions continues until completion. In case it is not met, suitable measures should be provided to attract operator attention.

7.2.3 Deliberate operator action should be required to return the EEPS to normal standby conditions.

7.3 Class III AC Power Supply System

7.3.1 Class-III AC Power supply system consists of Standby AC power supply source and AC distribution system.

Capacity and Capability

7.3.2 Each standby AC power source shall consist of a generating unit complete with all auxiliaries, accessories and a dedicated, separate and independent stored energy supply system (compressed air / DC battery) for starting power and fuel oil for running the prime mover.

7.3.3 The Standby AC power source shall have sufficient capacity and capability to start and continuously supply power to loads, within stipulated time, which will be connected to it in different scenarios during its entire life, while being subjected to most severe ambient conditions (temperature, pressure, humidity, etc.) expected at its location.

7.3.4 Maximum kW and kVAR demanded by loads (considering variation if any in the power demanded by the driven equipment and generator voltage and frequency variations etc.), load starting kVA and accelerating time, load sequencing, restarting of motor with certain base load etc. should be taken into account while estimating the capacity and capability of Standby power sources. Typically, a margin of 10% should be allowed between maximum operating load on the Standby power source and its rated capacity to cater to any future load growth.

7.3.5 The Standby power source should have an over load capacity of at least 10% of its nominal rating for a duration of two hours every twenty four hours or for a duration of one hour every twelve hours to provide assurance that it is capable of handling short time over loading at the onset of an event.

7.3.6 The total time duration for which the safety buses do not have power supply consists of time required for:

a) under voltage relay sensing and its actuation,
b) initiation of start signal to the Standby power sources,
c) starting and built up of voltage and frequency by the Standby power sources and
d) sequential restoration of safety loads after the energisation of safety buses,

7.3.7 The total interruption time for the safety loads should be consistent with the interruption time considered in the safety analysis for the plant.

7.3.8 Following should be taken into account for standby AC power sources[6]:

a) Each Standby AC power source should be independent and physically separated.
b) Standby AC power sources are expected to start reliably and accept the load a number of times when called upon during its design life in the event of loss of preferred power supply, and during and after DBE.
c) Standby AC power source should be capable of maintaining during steady state and transient operating conditions, voltage and frequency variations and the time required to restore them to their respective allowable values as defined for connected loads. Standby power source voltage wave form distortion, voltage unbalance should be within a range that will not degrade the performance of connected loads below acceptable limits.
d) The standby AC power source should be capable of continuous operation at design load following its operation at light load or no load without any stops for maintenance activities.
e) The standby AC power source may be utilized to the limit of their continuous and short time ratings. The light load and no-load operating regimes should be established in

[6] Stand by AC power sources are referred as Diesel Generator (DG) sets

consultations with the manufacturer of the standby power source and operated strictly within such limits including post no-load and light load operation requirements.

f) Adequate margin should be available between the over speed reached by the rotating parts of Standby power source during rejection of short time load and the over speed protection setting to guarantee that the unit will not trip on short-time rating load rejection. As a minimum, the generator rotor, exciter rotor (if used), and flywheel should be designed to withstand an over speed of 25% without damage for specified duration.
g) Vibration amplitudes should be limited to be within the design capabilities of the Standby AC power source and auxiliary components. Solenoids, relays, and other devices should be mounted in such a way to minimize vibration effects on them.
h) Harmful torsional vibration stresses should not occur within a range from 10% above to 10% below rated idle speed and from 5% above to 5% below rated synchronous speed.

7.3.9 Standby AC power source along with its accessories and auxiliaries shall be capable of performing the intended functions under the following:

a) under applicable conditions (ambient temperature and pressure, humidity, ambient combustion air quality, cooling water quality etc.) that are expected at the place of installation;
b) when using fuel of specified quality;
c) during and subsequent to specified design basis earthquake conditions;
d) external events which induce any common mode failure in standby AC power source and its auxiliaries may also be envisaged.
e) when subjected to specified load profiles expected under various operating conditions without exceeding acceptable voltage and frequency limits; and
f) even after operating for a specified period at no load or reduced load.

7.3.10 Standby AC power source shall be capable of starting, accelerating and accepting design load within a time acceptable for the intended safety function it performs. The Standby AC power source should be capable of starting:

a) from normal standby condition;
b) with cooling not available for a time equivalent to that required to bring cooling equipment into service using energy from the Standby AC power source itself; and
c) on a restart with an initial engine temperature equal to the stabilized full load engine temperature.

7.3.11 The standby AC power source should have an automatic start on loss of preferred power supply to the essential buses. The standby AC power source may also have an anticipatory automatic start on actuation of an emergency signal (without loss of power to the safety bus). The time taken to start the standby AC power source and to connect loads to this source should be consistent with the assumptions on startup time made in the safety analysis.

7.3.12 Energy required for starting of standby AC power sources should be independent of station electrical power sources and self-sustaining while running. In case, batteries are provided for the standby AC power source, these should be subject to surveillance to detect deterioration and failure, to the same extent as for any safety system battery. If any other mode of starting is utilized for starting of stand by AC power supplies, such systems should also be covered under surveillance programme.

7.3.13 Instrumentation and control systems used for the starting, coupling, running and protection of a standby AC power source should be supplied by batteries within their own division.

7.3.14 EEPS may supply loads of lower safety classification (including loads not important to safety) provided that the independence requirements are met. The isolation devices between emergency electric power system and equipment of lower safety classification should be part of the safety system.

Control & Monitoring

7.3.15 Provisions should be made in the design to control and monitor Standby AC power source from control room as well as from the local Standby AC power source control panel.

7.3.16 Transfer of EEPS bus from its standby AC power source to a preferred power supply should require manual action. Upon its disconnection, controls associated with standby power source should be restored to those applicable to normal auto standby condition.

7.3.17 Upon loss of preferred power supplies to the EEPS bus, the under voltage protection scheme or equivalent scheme associated with the EEPS bus should automatically trip loads connected to the EEPS bus.

7.3.18 Restoration of non-safety loads by automatic load sequencer should be carried out after restoring all safety loads connected to the standby AC power source.

7.3.19 If the standby AC power source is equipped to operate in both the isochronous and the droop mode, provisions should be made to automatically place the engine governor in the proper mode of operation when the standby AC power source is required to operate automatically.

7.3.20 If the voltage regulator of the standby AC power source is equipped to operate in the paralleled and non-paralleled mode, provisions should be made to automatically place the voltage regulator in the proper mode of operation when the standby AC power source is required to operate automatically.

7.3.21 Adequate surveillance instrumentation should be available near the standby AC power source and at the MCR to provide local and remote alarms, indications, abnormal, pre-trip and trip conditions. Standby AC power source including its auxiliaries should be continuously monitored for healthiness and identification of any abnormal condition unambiguously and also to facilitate its safe operation.

Protection systems

7.3.22 Protection devices that ensure protection of standby AC power sources from immediate catastrophic damages (Over speed, differential) should be in service in all modes of operation of standby power sources.

7.3.23 Protection devices that ensure protection of standby AC power sources from non- catastrophic damages (Jacket water temp, lube oil pressure, fuel oil pressure, electrical over current and earth fault protections, excitation protections etc.) should be bypassed when the standby AC power source is catering to loads under LOCA condition in order to avoid tripping of standby AC source on spurious actuation of the above protections.

7.3.24 Alternatively, if protective features other than engine over speed and generator differential current are retained during accident conditions, two or more independent measurements of each of these parameters with coincident trip logic should be provided. The design of the coincident trip logic circuitry should provide alarm for each individual sensor initiation. All protective devices should remain effective during the testing of standby AC power source, and during normal operation.

7.3.25 The design should provide for individual testing of each trip function and bypass function. All protection trip actuations for the standby power source should be annunciated in MCR.

Support systems for standby AC power sources

7.3.26 Support system equipment (e.g. ventilation systems, cooling water pumps and lubrication systems) for redundant division of the standby AC power sources should be supplied with power from the division it serves in order to preserve the redundancy and independence of the divisions.

7.3.27 The auxiliary systems and support systems of standby AC power sources should be sized for multiple starts.

Fuel for standby AC power sources

7.3.28 Stored energy (fuel) at the site shall be of sufficient quantity to operate the standby AC power source while supplying post-accident power requirements to a unit for the longer of the following:

a) 7 days
b) Time required to replenish the fuel from sources away from the generating units' site following the design basis event.

7.3.29 Non-availability of associated fuel supply system (pumps, submergence of vent lines of underground fuel storage tanks) to standby AC power source in case of an external event such as flooding will hamper the functionality of the system. Provisions should be made for:

a) Manual transfer of fuel to the day tank of standby AC power source which should be established and demonstrated.
b) Vent lines of the underground diesel fuel tanks suitably raised to prevent any water ingress into the tanks in case of flooding.

7.3.30 Manual transfer of diesel from underground storage tanks to day tanks of standby AC power source should also be available under degraded infrastructure following extreme external events.

7.3.31 Adequate provisions should be made such that diesel oil transfer pumps do not become vulnerable to common mode of failure.

7.3.32 Provisions for fuel oil storage tank level measurement should be made. Periodic fuel evaluation programme for standby AC power sources should be established at site to identify degradation of fuel and to initiate appropriate action.

7.3.33 Performance and Qualification of emergency standby DG sets should be as per IEEE-387.

Surveillance and Testing

7.3.34 Provision should be made for the periodic surveillance and testing of standby power sources during plant operation. A suitable test programme in line with IEEE-387, with post-test examination of wear parts should be formulated and conducted on standby AC power source.

7.4 Class II Uninterruptible AC power system

7.4.1 This system provides reliable, regulated and filtered uninterrupted AC power to loads connected and also minimizes the effects of electrical power supply disturbances and variations.

7.4.2 Uninterruptible AC power system should be provided to supply loads for equipment important to safety that require continuous AC power. Some plant designs may not need uninterruptible AC power systems. The modern instrumentation and control systems and loads requiring continuous power may be fed with DC power systems. Such an approach eliminates a source of failure.

7.4.3 Each division of an uninterruptible AC power system should consist of a power supply from a DC power system to an inverter, a power supply from the AC bus of the same division and a device for automatically switching between the two supplies.

7.4.4 Alternatively, the uninterruptible AC power system may consist of an uninterruptible power supply with a dedicated battery charger, battery and inverter. If an uninterruptible power supply is used, the recommendations and guidance given in section 7.5 for battery chargers and batteries also apply.

7.4.5 During the failure of DC-AC inverter, the maximum interruption time for restoration of Class-

II power supply should be commensurate with the interruption time tolerable for the connected loads without affecting safety.

7.4.6 Where a provision exists to connect any Uninterruptible AC power system bus to the redundant uninterruptible AC power system bus, transfer of supply from available to redundant bus should be carried out manually without jeopardizing the safety functions that it is serving.

7.4.7 The design of uninterruptible power supplies should be consistent with the characteristics and design requirements of the loads and the interactions between loads connected to the uninterruptible AC power system. The limiting case for capacity is usually station blackout.

7.4.8 For example, the design of static inverters should ensure that the voltage harmonics produced by the inverter itself, as well as by any non-sinusoidal loads, do not degrade the functions of the systems being supplied.

7.4.9 The size of UPS system (normally specified in kVA at a given power factor) is dictated by the loads and inrush currents imposed on it. It may not be economical to size UPS to meet inrush currents from large motors and short circuit current requirements. The above requirement can be met by a fast acting transfer switch for transferring the transient requirements to a bypass source of power and/or by restricting the transient inrush current during motor starting (through soft starter) or by selective loading of UPS system. Consideration should also be given to selection of fault clearing devices to compensate for lack of capability to supply high short circuit current.

7.4.10 An uninterruptible power supply should withstand a perturbation in its output, such as voltage sag or an interruption to the cycle, provided that such a perturbation does not result in a loss of the required function of the equipment being served by the supply or in any undesired action by the equipment.

7.4.11 The inverter of UPS system should be capable of operating over the input DC voltage variation expected during various modes of operation of the associated battery (e.g. float, equalizing and at the end of the discharge voltages).

7.4.12 The steady state and transient increase in DC voltage due to similar input AC voltage variations to the rectifier feeding the inverter or output DC over voltages generated by the rectifier should not cause tripping of the inverter.

7.4.13 UPS availability should be commensurate with the reliability requirement of safety loads it is supplying. The total time for which class II is required to be available for duty should be evaluated at AC output bus. This time is influenced by a variety of factors, such as UPS configuration, provision of bypass switching capability, the manufacturer's stated Mean Time Between Failures (MTBF), and Mean Time To Repair (MTTR) and routine maintenance schedules.

7.4.14 UPS system selection and design should conform to IEC-60146 and IEEE-944.

7.5 Class I DC Power Systems

7.5.1 Each division of a DC safety power system should consist of at least one battery, one battery charger and a distribution system. Additional safety-related batteries may be provided for special services such as cranking of Stand by AC power sources, engine driven firewater pumps etc.

7.5.2 In case non-safety DC loads are to be connected to safety DC buses, the requirements of independence criteria as given in this guide should be applied for such connections. The isolation devices between class I DC power system and equipment of non-safety classification should be part of the safety system.

If non-safety loads are considered for the entire duration of load cycle estimated for the design of DC batteries, their automatic disconnection may not be required. However, if disconnection of non-safety loads is taken in to account while arriving at the load cycle, a minimum time duration of 30 minutes should be considered for manual disconnection of such non-safety load connected to DC Battery unless automatic disconnection of such loads is carried out immediately on failure of input to the battery.

Battery

7.5.3 The battery must supply the power required by the connected loads in case of:

a) loss of AC power to the charger; or
b) charger failure; or
c) removal of the charger from service for maintenance

7.5.4 Each battery set should, without a battery charger, be capable of meeting all required load demands and conditions (including duty cycles and electrical transients) that occur in the plant states specified in the design basis, with taking account of factors as design margins, temperature effects, any recent discharge and deterioration with age.

7.5.5 In case battery is not dedicated to the inverter(s) the magnitude of ripple voltage should not exceed values permitted for equipment connected to DC bus.

7.5.6 A separate battery should be provided for each redundant safety group in each unit to provide the required independence between redundant groups as mentioned in Section 5.2.2 of this guide.

Battery capacity

7.5.7 The time period for which the battery should be required to supply the loads depends upon the time interval necessary to restore AC power (either from on-site power sources or off-site power source whichever is earlier) to the battery charger, following a loss of off-site power. Batteries providing backup to safety instrumentation, control and monitoring functions and emergency lighting should provide back up, without shedding of safety loads, for a duration determined by the plant safety analysis, subject to a minimum of 8 hours. Batteries providing back up to safety motor / power loads should provide back up for duration as determined by the plant safety analysis.

7.5.8 The limiting case for battery capacity sizing is normally SBO. Under SBO condition, capacities of class I power supplies should be integrated with demands imposed on them during SBO as established by the safety analysis. To extend the availability of class I power supplies during SBO condition predetermined load shedding may also be incorporated in operating procedures.

7.5.9 The battery capacity and sizing shall meet the requirement specified in IEEE-485 and the guidelines given below:

a) load cycle, i.e. the time versus load current profile should consider the requirements in all operating modes, including operation of a battery during manual change over from one charger to another charger;
b) permissible end of discharge voltage of the cell;
c) correction factor for ambient temperature variations at the place of installation (lower temperature limits);
d) loss of capacity due to ageing;
e) type of cell; and
f) Design margins.

7.5.10 A DC/inductive load such as a motor or an inverter, which requires constant power, demands more current as the battery voltage decreases. This increase in load current further results in a rapid discharge of the battery. Although this effect may be partially (or completely) offset by other resistive loads that demand less current as the battery voltage decreases, this should be considered when sizing the battery.

7.5.11 Ventilation should be provided in battery rooms to maintain the concentrations of combustible gases below prescribed levels. If forced ventilation is necessary:

a) The ventilation system for the battery room should be powered from the same division as the battery in the affected room.
b) Hydrogen monitoring should be considered.

7.5.12 While selecting batteries, consideration should be given for reliability and having monitoring facility (electrolyte level, state of charging etc.)

7.5.13 Batteries should be periodically tested and monitored as per IEEE 450 requirement, based on recommendations for each type of battery .The test should demonstrate the operability of the system and to detect any degradation.

7.5.14 The design aspect of battery installation should be in accordance with the AERB safety guide on Safety Classification and Seismic Categorization (AERB/SG/D-1) and on Fire Protection (AERB/SG/D-4).

7.5.15 Batteries should perform their intended function during and subsequent to specified design basis earthquake conditions.

Battery charger

7.5.16 Each battery should have its own battery charger. Battery charger should be sized keeping an adequate design margin and IEEE-946 should be followed while sizing the battery charger. In each redundant group, at least one battery charger and main distribution panel should be provided for each battery system. The battery charger shall be rated for supplying the loads and simultaneously charging the battery.

7.5.17 Standby battery charger can be provided to increase the operational flexibility and availability.

7.5.18 Harmonics injected into the input AC system of the battery charger and output ripples generated by the battery charger shall not degrade the performance of the systems to which it is connected and meet applicable clauses of IEEE-519.

7.5.19 In cases where the battery has to be removed from service for maintenance while the unit is in operation and the charger is required to supply connected loads for prolonged duration, then the necessary requirements should be specified. During such operation an increase in voltage regulation and output ripple should be expected. These increased values should be specified and should be within acceptable limits for connected loads. Alternatively provisions can also be made to provide DC battery back up to the affected bus from any other battery source of adequate capacity other than redundant group.

7.5.20 If the on-line battery charger cannot meet the requirements of charging the battery from a discharged condition within an acceptable time, a separate boost charger can be provided.

7.5.21 Each battery charger should have appropriate disconnecting devices in AC and DC circuits to enable the charger to be isolated.

7.5.22 During maintenance / testing of a charger, the available charger should be sized to supply both its own busloads plus the additional loads.

7.5.23 In case non-safety DC loads are to be connected to safety DC buses, the requirements of independence criteria as given in Section 5.2.4 of this guide should be applied for such connections.

7.5.24 The charger output voltage characteristics should be such that the battery will supply all momentary loads in excess of the charger capacity.

7.5.25 The rectifier/charger' output voltage should be maintained within its normal operating range for the entire range of input voltage variations. When the input variations go beyond the capability of the equipment, rectifier may be disconnected from the input. During this time battery should provide input power to the connected loads.

7.5.26 Battery chargers should be able to supply the loads without any battery connected. The ability to supply DC loads directly from the battery charger is part of the diversity in power supply for DC power systems. Operation in this mode is not normally expected.

7.6 Protection of DC Power Systems and Uninterruptible AC Power System

7.6.1 Protective devices should be properly sized, calibrated and coordinated so that only the faulty part of emergency electric power system is isolated without affecting the function of healthy part. Battery chargers, inverters and motor generator sets are sources of limited short circuit current. This will affect the sensitivity requirements for their protective devices.

7.6.2 The protection for battery chargers, inverters and motor generator sets should be coordinated with their associated alternative supplies, inverters, static switches, battery chargers, distribution panels, instrumentation panels and racks, and other equipment that they power.

7.6.3 Ground detection monitoring should be provided for isolated (ungrounded) DC power systems. The ground detection monitoring should sound an alarm before the impedance to ground falls below a value at which any malfunction could occur. Detection system to find feeder level identification where feasible may be considered.

7.7 AC Distribution System for Class III and Class II Systems

7.7.1 The buses and cables of emergency electric power system should be selected, rated and qualified for service considering normal operation as well as fault conditions. They should also qualify for environmental conditions taking into account cumulative radiation effects, if applicable, and thermal ageing expected throughout their design life including Design Basis Events. They should also be sufficiently fire retardant to prevent propagation of fires and limit smoke generation. Special attention should be given to qualification of wires and cables that have to withstand condition within the containment during and after a Loss of Coolant Accident (LOCA) at any time during design life as well as other adverse environmental conditions.

7.7.2 Buses and cables should have a voltage rating based on system voltage and system grounding and dielectric strength/impulse rating (if applicable) greater than any credible transient voltage to which they can be subjected.

7.7.3 Buses and cables should be of such size as to carry safely the currents of main and branch circuits required during voltage variations and the demand of loads during DBE without exceeding the allowable conductor temperatures throughout their life. Calculation of conductor temperatures should take into account the maximum environmental temperatures, normal or fault currents, load factors and arrangement of other cables in the same or nearby cable trays and other applicable de-rating factors. In addition, consideration should be given to the influence of cable spacing, wall penetrations, floor penetrations, fire stops and retardant coatings on the heat dissipation on cables. Fire protection aspects are to be considered as given in AERB safety guide on Fire Protection (AERB/SG/D-4).

7.7.4 Buses and bus-duct supports should be designed to withstand mechanical loads imposed on them during normal and fault conditions.

7.7.5 The electromagnetic interference from power circuits should be within acceptable value and follow applicable clauses of IEEE-1143 “Guide on Shielding Practices for Low Voltage Cables" and also ensure:

a) minimum distance of cable trays of power cables from trays of control cables;
b) possibility of heavy arcs affecting control cables and control signals;
c) electromagnetic interference due to switching-off or start-up of heavy-duty motors affecting control signals;
d) requirements of control/power cables shielding from electromagnetic effects; and
e) effect of communication cables and public address system cables on control signals.

7.7.6 Cable trays and their supports should be designed to withstand mechanical loads imposed by cables and associated fittings in addition to seismic loads.

7.7.7 The design of switchboard compartments, bus duct and other critical equipment should be suitably protected against dust, vermin etc. They should be protected against ingress of water depending on the type of installation (indoor/outdoor), and location or possibility of water ingress from any other sources. Suitable measures should be taken to avoid condensation of moisture.

7.7.8 Connectors, terminations and splices should be selected and qualified for their applications and the in-service conditions postulated to be experienced throughout their design life.

7.7.9 The design and installation of cables of safety system should meet the requirement given in IEEE-690.

7.7.10 Control and instrumentation cables, medium voltage power cables (650 V or less) and high voltage power cables (above 650 V and up to 33 kV) should be placed in separate cable trays, with adequate separation as per applicable standards.

7.7.11 Buses, cables, wires and switchboards of one redundant emergency electric power system group shall be physically separated and electrically isolated from the other redundant group distribution system as per requirement given in IEEE 384.

7.7.12 The requirements to prevent fire propagation are considered in AERB safety guide on Fire Protection (AERB/SG/D-4). Fire Survival (FS) cables should be used for safety circuits where independence of redundant safety circuits cannot be ensured due to various constraints. Use of Fire Retardant Low Smoke (FRLS) cables in general should be considered to minimize the hazards due to fire.

7.7.13 It may be considered necessary in special situations to operate safety system equipment in overloaded conditions to ensure fulfilment of certain safety actions. This should be taken into account at the design stage. For example, the set points of circuit protective devices may be set above the levels necessary to protect the equipment from damage due to overloads. Where this is the case, the overloaded equipment should not adversely affect either the other circuits or associated equipment to such an extent that their respective functions are impaired. The continued operation of safety system equipment in overloaded conditions with the consequent risk of destruction should not form part of the safety justification for design basis accidents, although it is recognized that unforeseen circumstances may arise. It should also be noted that if circuit protective devices are set at higher level, an undetected overload could remain on the system under normal operating conditions, thus possibly accelerating failure of equipment needed in special situations. Appropriate monitoring should be provided by means of over current/over temperature alarm that prevents any sustained overload conditions from remaining undetected.

7.7.14 AC supply to auxiliary devices required for operation of equipment associated with a load group should be supplied from a related AC bus section to prevent loss of one redundant group of supply due to equipment failure in the other redundant group.

7.7.15 Any power/control cables of EEPS located in safety class structure and connecting systems located in non-safety class structure should be provided with qualified safety class isolating devices located in the safety class structure. Circuit breakers, contacts of relays, fuses, optical isolators etc. are some of the devices which may be considered for isolation. Non-safety class cables should be run in a segregated manner so as not to affect the safety class circuits due to its failure. Else, the non-safety circuits should be considered as associated circuits and the requirements as mentioned in 5.2.21 should be followed.

7.8 DC Distribution System for Class I Systems

7.8.1 The distribution system should consist of all equipment in the distribution circuit from its incoming supply isolation device and up to the loads. Each distribution circuit should be capable of transmitting sufficient energy to start and operate all required loads in that circuit.

7.8.2 Distribution circuits to redundant equipment should be physically and electrically independent of each other. There should be no provision for automatically transferring loads from one redundant supply to another. Manual transfer of safety-related loads of a dead bus to available redundant healthy bus is done when the dead bus is totally isolated, no protection relays operated prior to the transfer and no abnormality exists on the dead bus.

7.8.3 Power supply to auxiliary devices associated with EEPS equipment belonging to a safety division should be supplied from a related bus section of the same division to prevent loss of one division of supply due to equipment failure in the other division.

7.8.4 Any power/control cables between EEPS located in safety class structure and systems located in non-safety class structure should be provided with a qualified safety class isolating devices located in the safety class structure. Otherwise the non-safety class cables should be run in a segregated manner so as not to affect safety class circuits due to its failure. Refer 7.7.15 above for examples of isolating devices.

7.8.5 Cross-ties between DC distribution buses may be used to supply critical loads when a battery or charger is taken out of service for maintenance or testing. Cross-ties can also provide additional switching flexibility during abnormal situations, which help in carrying out orderly shutdowns. A cross-tie to any independent battery system, other than the battery in the redundant safety group is acceptable for all operating modes provided the independent battery system meets the load requirements of safety related battery system, including the sizing requirement of Battery and Battery charger. A cross-tie to a non-safety related battery system is also acceptable, however, its use may be limited during normal operation of the unit. An acceptable design provides a manually operated circuit breaker/isolation device at each end of the cross-tie which should be normally open and should activate an alarm in the main control room if either is closed. Operating procedures should clearly define the operation of these cross-tie breakers.

7.8.6 Circuit breakers, fuses, or manual isolating devices should be provided between battery terminals and the main distribution bus and also between battery charger and the main distribution bus. Off normal position of these breakers should activate alarm in the control room.

7.8.7 The buses in main distribution panel should be insulated to minimize the probability of bus fault. For connections between battery and distribution board, the designer should consider separate armoured single core cables for positive and negative leads or unarmoured cables in separate nonmagnetic conduits or segregated bus ducts so as to ensure that pole to-ground fault can only occur instead of pole-to-pole fault. Physical barrier should also be provided between positive and negative terminal connections at the main distribution panel.

7.8.8 The distribution bus and any manual isolating device should have the capability to withstand the maximum short circuit current for a specified time.

7.8.9 The continuous current rating of the protective/isolating device should be selected to take care of maximum sustained current in the battery duty cycle. The protective device should have the following trip rating:

a) sufficiently high to prevent deterioration of the fuse element or opening of the circuit breaker due to momentary or short time load cycle current rating of the battery or circuit; and
b) sufficiently low to assure opening for short circuit current available from the battery at the end of discharge voltage

7.8.10 Specifications for equipment/components powered by DC systems should be such that the equipment can be operated without any damage due to input voltage variation under various states of the battery system when connected.

7.8.11 Supply cables for DC powered components should have adequate voltage rating and should be sized based on ampere capacity to take care of the worst case operation.

7.8.12 Surge suppression networks are recommended for use in the DC system to overcome voltage spikes caused by highly inductive loads which may generate surges when de-energized, if not suppressed.

7.8.13 Design features of each DC system should provide an effective and safe means to perform a periodical capacity discharge test on each battery.

7.8.14 The controls of battery and its related charger should be provided in the same area to maintain the independence criteria. Switching devices associated in battery system should be provided so as to perform all operations locally and monitoring alarms should also be provided at MCR.

8. DEC POWER SUPPLIES

8.1 General

8.1.1 DEC power supplies shall be provided to protect NPP against SBO (simultaneous failure of off-site and emergency electric power supplies excluding battery fed supplies) and other DECs. This needs AC and/or DC power supplies that are diverse in design and are not susceptible to the events that caused the loss of on-site and off-site power sources. Refer Fig. 2 for typical arrangement of connection between EEPS and DEC power sources.

8.1.2 Electrical, Control and Instrumentation loads required to be fed under DEC shall be identified. The DEC power supply shall be capable of supplying the necessary electrical power to plant loads required to prevent significant core and spent fuel degradation, mitigate the consequences of DECs and monitoring of essential plant parameters following DEC, in the event of the loss of the off-site power combined with the failure of the emergency power source.

DEC power supplies shall be capable of powering required equipment till preferred power (either through off-site sources or standby sources) is made available.

8.1.3 The DEC power supply shall be capable of supplying the necessary electrical power to plant loads required to mitigate the consequences of DECs involving a loss of off-site power combined with the failure of the emergency power source, for design basis accidents.

8.1.4 At a multi-unit site, DEC power supplies may be provided for each unit or shared by multiple units. Where the DEC power supplies are shared, the capacity and capability of DEC power system should be adequate to meet the simultaneous demands from all units which share the DEC power source.

8.1.5 DEC power supplies shall be located at the NPP and shall be under the control of the plant operators.

8.1.6 The DEC power supplies shall be adequately protected from extreme external hazards and suitably located so as to enable plant personnel timely access to the location of DEC power supplies, facilitate its manual start and connect to required loads within the autonomy time of the plant batteries or within the time determined by the safety analysis of the plant.

8.1.7 If EEPS or a portion of EEPS is used to deliver electrical power from DEC power supplies to required loads, it should be accomplished only after EEPS has been disconnected from other power supplies and verification of its healthiness.

8.2 Qualification

8.2.1 The DEC power supplies with auxiliaries shall be qualified for their intended application.

8.2.2 Design should ensure functional capability of DEC power supplies under extreme environmental conditions and after extreme external hazards applicable for its location at the NPP.

8.2.3 Structures housing for DEC power supplies should remain functional after being subjected to extreme external events

8.3 Design for Reliability

8.3.1 The DEC power sources shall be independent and physically separated from the emergency power supplies and off-site power supplies.

8.3.2 No single point of vulnerability should exist whereby a weather related event, external event or a single failure could disable unit's standby AC power supplies, all off site power supplies and simultaneously cause the failure of the DEC power supplies.

8.3.3 The DEC power supplies are provided to ensure safety under Design Extension Conditions, hence, the possibility for the application of design principles such as redundancy, single failure criteria, qualification etc. as applicable in case of EEPS should be explored. However, emphasis should be to provide diversity and consideration should be given to the repair and replacement potential, should a failure occur.

8.3.4 DEC power supplies should be capable of continuous operation for duration of 7 days without any assistance from off-site for fuel, lubricants or any other consumables.

8.3.5 In order to ensure complete independence of the DEC power supplies from the EEPS or off site power supplies, they should be self-contained in all respects including power required for starting, excitation, control and logics etc.

8.3.6 If DG set is used as a DEC power source, it should be preferably cooled by self-contained radiator provided with shaft mounted fan for air cooling.

8.3.7 Fuel oil and lubricating oil required for continuous 8 hours of operation of DEC power sources should be available close to the source and protected from extreme external events. Auxiliaries such as room ventilation, lighting etc. for the building housing DEC power supplies should be provided with electrical power from DEC power sources.

8.3.8 Necessary tap-off connection at equipment/EEPS for facilitating connection of DEC power source should follow the principle of diversity (e.g; locating connection points at different elevations, different buses, or different areas of the plant or geographically at diverse locations of the plant).

8.3.9 The DEC power supply scheme should be designed considering minimum number of switching operations, preferably from one or two locations to facilitate timely extension of power to essential loads.

8.4 Stationary/Portable Power Supplies

8.4.1 The plant design should include the necessary features to enable the safe use of non-permanent power sources, instruments etc. to enable effective monitoring of plant status e.g. identification of terminals of panels / marshalling boxes / JBs and providing suitable terminals to facilitate connection of portable instruments, providing suitable power supply change over switches in panels where portable power supplies may be required to be used under DEC.

8.5 Maintenance & Testing

8.5.1 Provision should be made in design for carrying out commissioning, surveillance, testing, in-service inspection and maintenance of dedicated power supply system equipment.

8.5.2 All DEC power supplies, portable power supplies, instruments, connections etc. provided for use during DEC should be subjected to an In-Service Inspection and test programme.

8.5.3 Hook-up arrangement of the DEC power supply to the identified loads should also be tested periodically. Power terminals at hookup points/JBs should be properly and very distinctly identified with R, Y and B phases of 3 phase supply system (so as to ensure required direction of rotation of 3 phase motor loads connected to hook up points), Phase and neutral of a single phase supply, +ve and –ve terminals of a DC supply system.

8.5.4 Where mobile power supplies are considered in the design as DEC power supply, procedure should be developed along with a detailed check list so as to ensure correct termination of mobile source to hook up points or to portion of EEPS. Before connection, adequate care shall be taken to ensure proper isolation of existing supplies, if any, and correctness of phase and polarity of supply and loads for their correct operation.

8.5.5 It is preferable to ensure availability of suitable lengths of cable ends with previously connected plug and socket arrangement duly tested and ready for hookup at both the ends.

9. SPECIFIC PROVISIONS FOR ENHANCING SAFETY FURTHER

The provisions and means that should be provided to enhance safety further are as follows:

9.1 Enhanced Off-site Power Supply Systems

9.1.1 The diversity and reliability of off-site power sources and associated systems should be maintained by such means as multiple power transmission lines from diverse routes and sources, improved seismic resistance of the switchyard and substations.

9.1.2 In case of damage to the off-site power supply lines and to the station switchyard during an external event, it is important that these be repaired and brought back into service at the earliest. Necessary preparedness for this purpose including stocking requisite spares (such as additional high voltage and temporary cables along with backup electrical equipment compatible with existing switchyard and substations) and logistics of obtaining services of expert agencies should be provided.

9.1.3 Site should carry out a detailed study to assess the components in switchyard that are vulnerable to damage, spares required to be stored at site and expertise required to be outsourced for specialized jobs to bring back switchyard and the grid on line within a short period, subsequent to an earthquake/flooding/cyclone.

9.1.4 The responsible organization should implement administrative arrangements (including staff availability, training, etc.) to guarantee that nuclear power plants are the priority 'consumers' to have electrical supply restored from the national or regional grid.

9.2 Enhanced On-site Power Supply Systems

9.2.1 Emergency electric power system and DEC power supplies should be located above flood level due to extreme natural events or should be provided with additional measures to protect from the same as per Concept of 'Dry site' [7] for new NPPs.

9.2.2 Functional capability of equipment should also be ensured by providing procedures and training on the use of electrical equipment especially portable power sources under harsh environmental conditions during severe accidents.

9.2.3 Load segregation should be done at design stage to identify the power requirements and monitoring and control requirements for performance of necessary safety functions. Integrity of monitoring and control loop should be ensured under all plant states.

9.3 Additional Provisions

9.3.1 In addition to DEC power source(s) which are centrally provided to meet the consequences of DEC, on site availability of following portable equipment, located at a secure and identified place (s) are generally useful and provision of the same should be considered by the NPP operator:

(a) AC/DC rectifier power supply modules suitable to receive input from DEC power sources/portable generators and generating output matching with the requirements of essential instruments required to monitor the NPP under DEC.

(b) Battery cells of required voltage useful to monitor the essential plant parameters with available portable instruments.

(c) Portable engine driven generators having output voltage matching with the plant requirements to facilitate charging of plant batteries required for monitoring plant status, or operate small process load.

(d) Hand held lamps with batteries,

[7] Concept of 'Dry site' - Protection against flooding by adopting high safe grade level rather than by flood protection measures like bunds/dykes.

(e) Portable instruments for measuring electrical resistance, voltage, current etc. with range and accuracy compatible with that required for measuring plant parameters directly from field sensors.

(f) Flexible cables of different lengths suitably terminated and with cores identified.

9.3.2 Provision of self-sufficient (e.g. solar powered) lighting system for locations where operator presence is expected during DEC may enhance operator convenience. However, credit for the same should not be taken unless such systems are qualified for extreme external events.

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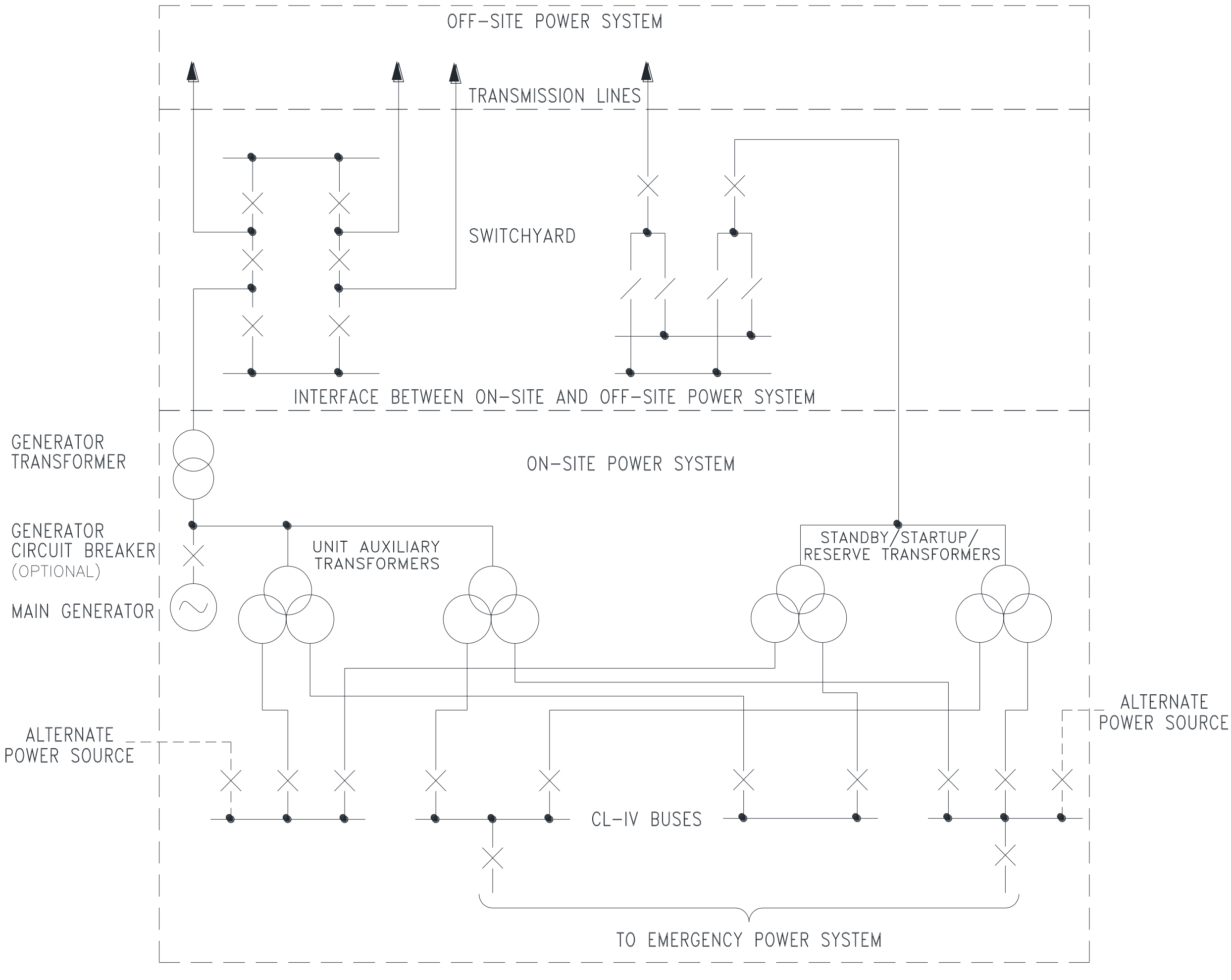

Fig 1: Typical relationship between off-site power system and on-site power system

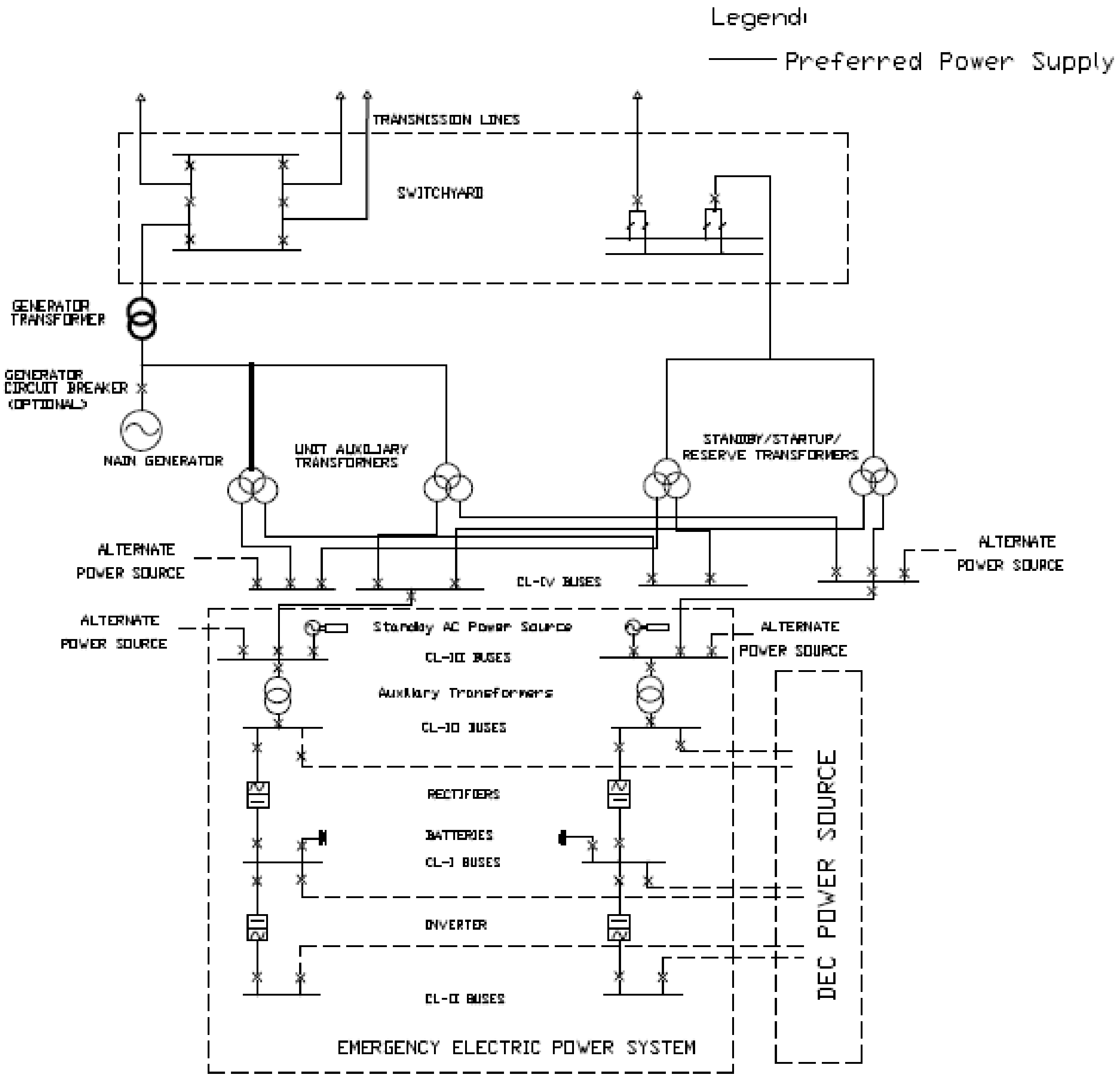

Fig 2: Typical relationship between preferred power system, emergency power system and DEC power sources

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September 25 & 26, 2017
October 13, 2017
October 27 & 28, 2017
November 17, 2017
November 27, 2017
December 22, 2017
January 31, 2018
February 5, 2018

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