AERB SAFETY GUIDE NO. AERB/SG/D-11

EMERGENCY ELECTRIC POWER SUPPLY SYSTEMS FOR PRESSURISED HEAVY WATER REACTOR

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FOREWORD

Safety of public and occupational workers and the protection of environment should be assured while activities for economic and social progress are pursued. These activities which include establishment and utilization of nuclear facilities and the use of radioactive sources have to be carried out in accordance with relevant provisions in the Atomic Energy Act, 1962.

Assuring high safety standards has been of prime importance since inception of the nuclear power program in the country. Recognising this aspect, the Government of India constituted the Atomic Energy Regulatory Board (AERB) in November 1983 vide Standing Order No. 4772 notified in the Gazette of India dated 31.12.1983. The Board has been entrusted with the responsibility of laying down safety standards and framing rules and regulations in respect of regulatory and safety functions envisaged under the Atomic Energy Act, 1962. Under its programme of developing safety codes and guides, the AERB has issued four codes of practice in the area of nuclear safety covering the following topics:

Safety in Nuclear Power Plant Siting.

Safety in Nuclear Power Plant Design.

Safety in Nuclear Power Plant Operation.

Quality Assurance for safety in Nuclear Power Plants.

Safety guides are issued to describe and make available methods of implementing specific parts of relevant codes of practice as acceptable to AERB. Methods and solutions other than those set out in the guides may be acceptable if they provide at least comparable assurance that Nuclear Power Plants (NPPs) can be operated without undue risk to the health and safety of plant personnel, the general public and the environment.

Codes and safety guides may be revised as and when necessary in the light of experience as well as relevant developments in the field. Annexures, footnotes, references and bibliography are not to be considered integral parts of the document, but included to provide information that might be of help to the user.

Emphasis in these codes and guides is on protection of site personnel and public from undue radiological hazards. However, for aspects not covered in codes and guides, applicable and acceptable national and international codes and standards shall be followed. In particular, industrial safety shall be assured through good engineering practices as well as compliance with Factories Act, 1948 as amended in 1987 and the Atomic Energy (Factories) Rules, 1996.

This safety guide is one of a series of guides, already prepared or are under preparation as a follow-up of the Code of Practice on Design for Safety in Pressurised Heavy Water Based Nuclear Power Plants (AERB/SC/D). The guide is based on the current design of 220 MWe and 500 MWe PHWRs. This safety guide specifically provides guidance on all aspects of safety in designing an emergency electric power supply system and about the basic requirements of other types of power supply systems in NPPs.

AERB staff and other professionals from BARC, IGCAR and NPC have prepared this safety guide. In its drafting, the relevant International Atomic Energy Agency (IAEA) documents under the Nuclear Safety Standards (NUSS) programme, especially the IAEA safety guide on "Emergency Power Systems of Nuclear Power Plants" (50-SG-D-7) and other international standards have been used extensively. The guide has been reviewed by experts and vetted by Advisory Committees before issue. AERB thanks all individuals and organisations involved in its preparation. List of individuals, who have participated in committee meetings, along with their affiliation, is also included for information.

(Suhas P. Sukhatme)
Chairman, AERB

DEFINITIONS

Design Basis Events (DBE)

A set of events that serves as part of the basis for establishment of design requirements for systems, structures and components within a facility. DBE includes normal operation, operational transients and certain accident conditions under Postulated Initiating Events (PIE) considered in the design of the facility.

Electrical Grid

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

Electrical Separation

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

Emergency Electric Power System

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

House Load Operation

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

Islanding Mode of Operation

In the event of unsuccessful load shedding and continuing deterioration of the grid condition, to prevent catastrophic failure of the whole grid, a part of the identified grid along with one or more generating units separates from the main grid and operates in an islanding mode of operation with voltage and frequency of the system within acceptable limits.

Isolation Device

The device in a circuit which isolates one section of the circuit from the other(s) to prevent malfunctions in one section of a circuit causing unacceptable influences in the other circuit.

Normal Power Supply

Power supply derived from the grid via transmission lines. In the case of nuclear power plant, the power supply is derived from the grid via transmission lines or plant generator or a combination of these.

Off-site Power Source

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

On-site Power Source

The electric power supply source located within the nuclear power plant and controlled by the nuclear power station operators.

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 from and including sensors, which generate a signal for protection.

Station Black Out (SBO)

A complete loss of AC electric power supply sources of an unit, both off-site and on-site, including plant generation.

Uninterrupted Power Supply (UPS)

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

CONTENTS

1. INTRODUCTION

1.1 General

1.1.1 Many systems in a Nuclear Power Plant (NPP) require power in order to perform their functions, in operational states and during and/or after Design Basis Events (DBE). The electrical power system of an NPP comprises normal power supply and emergency electric power supply.

The normal power supply derives power from the grid, plant generator or some combination of these. This power supply is generally referred as class IV power supply system and is interruptible for longer duration without affecting the safety of the reactor. Class IV supply system is also used to provide power supply to emergency electric power supply.

1.1.2 The purpose of emergency electric power supply is to supply and distribute electrical power to safety-related systems and to other designated items important to safety. In order to perform safety functions required during different DBE, safety systems are supplied by a reliable power supply in a variety of forms, arrangements and in combinations of redundancy and diversity.

1.1.3 The prime requirement of emergency electric power supply is high reliability. The required reliability level in a particular plant depends on the specific situation at plant site like the following:

- susceptibility to natural and man-induced events;
- plant configuration (single or multi-reactor);
- plant design (inherent heat removal capability, plant generator capability etc.); and
- nature of normal electric power supplies (small or large, stable or potentially unstable) etc.

1.2 Objective

The objective of this Guide is to elaborate basic safety requirements set out in the AERB Code of Practice on Design for Safety in Pressurised Heavy Water Based Nuclear Power Plants (AERB/SC/D, 1989) and to provide guidance for the designer.

1.3 Scope

1.3.1 The guide particularly covers design safety aspects of emergency electric power supply systems and in general about the associated interface with off-site and normal power supply systems of NPPs. Since the reliability of on-site power supply depends on the quality of off-site and normal power supply, the basic design requirements of these power supplies are covered in general.

1.3.2 The guide does not include requirements of power supplies for instrumentation and controls as they are dealt with in AERB safety guides on Safety Critical Systems (AERB/SG/D-10) and Safety Related Instrumentation and Control (AERB/SG/D-20).

1.3.3 The 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 SUPPLIES

2.1 General

2.1.1 The various electrical power supplies in a NPP can be classified as follows:

- off-site power supply system;
- normal power supply system; and
- emergency electric power supply system.

2.1.2 The off-site power supply system and normal power supply system are not safety-related systems.

2.1.3 Classification of electrical power supply systems is covered in section 3.19 of this guide. Ref: Fig 1A for a schematic representation of different classes of emergency electric power supply systems with their boundaries. Power supply requirements for instruments and control systems are covered in AERB safety guides on Safety Critical System (AERB/SG/D-10) and Safety-Related Instrumentation and Control (AERB/SG/D-20).

2.2 Off-site Power Supply Systems

2.2.1 The AERB Code of Practice on Safety in Nuclear Power Plant Siting (AERB/SC/S, 1990) covers aspects related to power evacuation of a given site. The AERB Code of Practice on Design for Safety in Pressurised Heavy Water Based Nuclear Power Plants (AERB/SC/D, 1989) covers aspects relating to emergency electric power systems and off-site power systems.

2.2.2 A minimum of two transmission line connections shall be provided between the plant switchyard and the grid and both should be operating simultaneously for better reliability. These two connections from the grid to the plant provide power supply to the normal power supply system. Distribution system shall be designed to minimise the simultaneous loss of two transmission connections as a result of failure of transmission equipment (like a transmission tower, a single breaker, switchyard bus, switchgear bus or cable). These transmission lines need not necessarily be routed through separate rights of way.

2.2.3 A common take-off structure used for two off-site circuits is acceptable if there are more than two off-site connections to the switchyard.

2.2.4 System studies should be performed 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; and

(e) loss of a transmission line of NPP switchyard.

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

2.2.6 The following may be reviewed and considered to improve the availability of off-site power source:

(a) feasibility of plant operation at house load should be established during design, commissioning and prior to commercial operation of the plant;

(b) islanding mode of operation of the station may be reviewed and considered in consultation with State Electricity Boards. Schemes for islanding mode of operation should be developed based on load flow 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. During islanding mode of operation the voltage and frequency variations and load variations should be within the capability of NPP. The scheme may also be developed as single level or multilevel islanding based on local requirements;

(c) consideration of suitable interconnection through grid with nearby hydro/gas based power station for drawing the power required to maintain the reactor in safe shutdown condition, and

(d) feasibility of supplying off-site power to normal power supply system using 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 and if applicable, established before commercial operation of NPP. This will help in establishing availability of another source of class-IV power supply.

2.3 Switchyard

2.3.1 The function of switchyard is to provide an interface between off-site sources and normal power supply. Switchyard should have a minimum of two buses. Switchyard shall be designed as per Indian Standards and Code of Practices.

2.3.2 Where only two transmission lines exist between the grid and switchyard, the physical design of switchyard should minimise the probability of a single equipment failure causing simultaneous or subsequent loss of both transmission lines. In case more than two transmissions lines are provided between the grid and switchyard, the design should ensure the availability of at least one transmission line subsequent to the failure of any single equipment.

2.3.3 In the event of loss of one of the power supply sources to normal power supply buses, an automatic bus transfer system shall be provided to restore power to the affected bus from the other supply source.

2.3.4 When transfer schemes are used to change the incoming power supply from one source to another source of normal power supply, the following can be practiced:

(a) manual transfer schemes;

(b) automatic live bus transfer; and

(c) automatic dead bus transfer.

2.3.5 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.

2.4 Normal Power Supply System

2.4.1 The normal power supply to an NPP is derived from plant generator and grid. 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 start-up transformer (SUT) of any unit or partly by UAT and partly by SUT. During shutdown of the unit, the station auxiliary loads can be supplied through SUT 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.

2.4.2 The normal power supply to NPP shall be designed in such a way that outage of one UAT or SUT does not affect the normal operation of power plant. The quantities and capacities of these transformers shall be designed accordingly.

2.4.3 Two or more circuits from the normal power supply sources to emergency electric power supply system shall be provided. A typical arrangement of connection between normal power supply and emergency electric power supply is shown in Fig.1B.

2.4.4 Each circuit of normal power supply connections to emergency electric power supply shall 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 DBEs.

2.4.5 The normal power supply and emergency electric power supply systems shall be connected through a safety-related isolating device (e.g. circuit breaker) located within the boundaries of emergency electric power system.

2.4.6 When connected to emergency electric power supply systems, any unacceptable degradation in this bus shall be alarmed and automatically disconnected from the normal power supply. Subsequently the power supply shall be restored from safety related emergency diesel generators.

2.5 Monitoring and Control Requirement

The following monitoring and control for normal power supply system connections to emergency electric power supply shall be provided in the main control room:

(a) status indication and control of circuit breakers;

(b) DC control supplies under-voltage alarm for circuit breakers;

(c) an alarm to sense unacceptable voltage degradation; and

(d) voltage and frequency indication at bus level.

2.6 Multi-Reactor Consideration for Off-site Power Supplies

2.6.1 At a multi-unit station, off-site power supply sources and switchyard may be shared between multi-units.

2.6.2 Shared circuits shall simultaneously supply all loads required for each design mode of operation of multi-units.

2.6.3 Status indication of shared circuit breakers shall be available in the main control room of each of the units, which share these facilities.

2.7 Alternate Power Sources

There may be alternate on-site or off-site power sources that can be used to increase the reliability of power supply to emergency electric power supply buses but which are not part of these systems (e.g. hydro/gas based station). At a multi-reactor site, an important feature in this context is the ability to feed power to emergency electric power supply 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 emergency electric power supply systems. The reliance placed on them whether they are connected, automatically or manually, will depend on many factors such as the reliability 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.

Refer Fig.2A/B for a typical AC power supply arrangement and alternate power sources/supply connections.

3. GENERAL DESIGN PRINCIPLES OF EMERGENCY ELECTRIC POWER SUPPLY SYSTEMS

3.1 General

This section covers design principles for emergency electric power supply systems and associated equipment for nuclear power plant. Emergency electric power supply systems include:

(a) alternating current power system; and

(b) direct current power system.

3.2 Design Principles

3.2.1 Emergency electric power supply systems shall be designed to ensure the availability of power supplies to equipment and systems that are essential to:

(a) shutdown the reactor;

(b) maintain the reactor in safe shutdown state;

(c) containment isolation;

(d) reactor core cooling; and

(e) prevent significant release of radioactive material to the environment under DBE.

3.2.2 During conditions as mentioned in 3.2.1 above, the voltage and frequency variations for emergency electric power supplies shall be within the capability of equipment connected to emergency electric power systems.

3.3 Design Basis

3.3.1 A specific set of design basis shall be established and used to design emergency electric power supply systems. It shall define the required functional tasks, the characteristics, the performance objectives, the operating and environmental conditions, and reliability consistent with the requirements of systems important to safety. Reference shall be made to paragraph 0312 of AERB Code, AERB/SC/D, 1989.

3.3.2 The design basis shall generally include the following and for details refer section 4 of this guide:

(a) those DBEs defined for the plant that require the services of emergency electric power supply systems;

(b) adequate redundancy and diversity criteria shall be applied to achieve the required reliability, of the emergency electric power supply system design;

(c) variables (e.g. voltage, current and frequency) or combinations of variables that should be monitored to initiate appropriate corrective action;

(d) environmental conditions like ambient temperature, pressure, humidity, vibration etc. to which emergency electric power supply systems are subjected to during normal operation and during and after DBE;

(e) identification of all loads including their characteristics powered by the emergency electric power supply systems. Distinction between those that are important to safety and those that are not, and identification of their power supply requirements;

(f) the time sequence in which the emergency electric power supply systems are required to supply energy to the loads so that they can meet their functional requirements for their intended duration;

(g) the required performance parameters of all emergency electric power supply system components;

(h) operating conditions for power supplies of emergency electric power supply systems, including conditions under which it is permissible to connect, disconnect and shutdown power supplies;

(i) provisions made for maintaining and testing different components of emergency electric power supply systems to enable confirmation of satisfactory performance, as per approved procedure;

(j) the required minimum duration of the capability of emergency electric power supply systems;

(k) identification of alternate power sources, if provided;

(l) consideration of station blackout;

(m) those conditions such as electrical short circuits and mechanical damages that could degrade the emergency electric power supply systems against which protection should be provided;

(n) identification of acceptable ranges of steady state and transient conditions (for e.g. voltage and frequency) occurring during a DBE to which the emergency electric power supply systems may be subjected to when required to perform;

(o) consideration of human factors as defined in AERB/SG/D-20;

(p) compliance to the requirements of Indian Electricity Rules and Bureau of Indian Standards and/or other standard/code of practices as applicable; and

(q) compliance to the requirement of AERB safety guides on Safety Classification and Seismic Categorisation (AERB/SG/D-1) and Fire Protection (AERB/SG/D-4).

3.4 Reliability

The reliability of emergency electric power supply systems serving the safety-related systems shall be such that the overall core melt frequency is not exceeded as given in the Design Safety Code (AERB/SC/D) and guided under all DBEs as specified in the design safety guide on Design Basis Events (AERB/SG/D-5).

3.5 Monitoring and Control

3.5.1 The design shall provide monitoring and controls in the main control room for emergency electric power supply system. Design shall also provide appropriate monitoring and control at local control panels/points as per AERB design safety guide on Safety Related Instrumentation and Control (AERB/SG/D-20).

3.5.2 Instrumentation and control equipment of emergency electric power supply systems required to perform their safety functions is considered as part of this system and therefore classified as safety support systems.

3.5.3 Controls of emergency electric power supply systems should be automatic or manual depending on the requirement. Manual control should only be accepted if it meets the requirements specified in the AERB Safety Code, AERB/SC/D, 1989 paragraphs 337-341. The functions of controls should include:

(a) before connecting standby DG set or alternate power supplies to emergency electric power bus, the loads as specified in design shall be disconnected automatically;

(b) automatic start and connection of the standby DG set and pick-up of the loads to the distribution system in proper sequence. This should be within reasonably short time periods to match safety-related functional requirements of process system; and

(c) manual synchronisation of standby DG set to normal supply when the latter is being reinstated and vice-versa.

3.5.4 In addition to automatic control, manual control shall also be provided to:

(a) permit switching of various available supplies and loads as required; and

(b) facilitate various modes of operation, i.e. service, testing, maintenance and repair.

3.5.5 Electrical isolation devices used in instrument and control circuits shall also be part of emergency electric power supply systems and shall conform to the requirements of concerned circuit. This is required to maintain the independence of redundant circuits and equipment so that safety functions required during and after any DBE can be carried out.

3.5.6 All electrical isolation devices for instrumentation and control circuits shall be such that maximum credible voltage or current applied to the device output due to shorts, grounds or open circuits occurring at the output will not degrade the circuit connected to the device input below an acceptable level.

3.6 Identification

Components of emergency electric power supply systems shall be distinctly marked or labeled. In addition, within the emergency electric power supply systems, redundant groups shall be suitably identified to reduce the likelihood of inadvertent maintenance, test, repair or calibration on an incorrect group. Such identification should not require reference to drawings, manuals or other reference material. Components or modules mounted in equipment or assemblies that are clearly identified as being in a single redundant portion of the emergency electric power supply systems do not require identification.

3.7 Common Cause Failure

3.7.1 The possibility of common cause failure, which could render emergency electric power supply systems unavailable to perform their safety functions when called upon, shall be considered in the design. The principles of 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 or from human involvement (e.g. operations and maintenance).

3.7.2 The principle of diversity should also be used as appropriate. For this purpose use of independence principles helps to ensure that primarily random equipment failure rather than identifiable common cause failure (fire, flood etc,) dictates the overall system unavailability. However, the possibility of other common cause failures, which may affect these principles should also be considered (e.g. poor fuel oil quality of DG set). AERB Design Safety Code, AERB/SC/D, 1989 suggests the use of diversity in this context.

3.8 Independence

3.8.1 Redundant groups of emergency electric power supply systems shall be physically separated and functionally isolated to achieve the principle of independence. Physical separation of circuits and equipment shall be achieved by using structures, distance, barriers or combinations thereof, depending on the need to protect against all DBEs (for e.g. fire, chemical explosion or internal missiles). The requirements of design safety guides on Fire Protection (AERB/SG/D-4) and Design Basis Events (AERB/SG/D-5) shall be accomplished. Functional isolation of groups shall be achieved by preventing failure in one group leading to unavailability or faults in another group.

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

3.8.3 The independence of safety system circuits and equipment shall not be compromised by functional failure of safety system support features. For example, a safety system support feature such as room ventilation (including standby equipment) shall be assigned to the same group of the emergency electric power supply systems, which it supports. This will prevent loss of mechanical function in one group from causing loss of electrical function in another.

3.8.4 Non-safety systems (e.g. turbine lube oil pump and generator seal oil pump) that are supplied from the emergency electric power supply systems shall be connected with safety grade isolation equipment. Such connections shall not reduce the functional independence or system reliability of the emergency electric power supply systems below a level required for them to perform their safety functions.

3.8.5 One way to realise independence is the use of dedicated power supplies for individual safety system components and provision of proper physical separation and protection.

3.9 Redundancy and Diversity

3.9.1 Emergency electric power supply systems shall be divided into two or more independent and redundant groups. The redundancy shall be consistent with that of the safety systems served. Each group shall have the reliability necessary to permit the systems it serves to fulfil their safety functions.

3.9.2 The level of redundancy should also take into account any increased unavailability of emergency electric power supply 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 emergency electric power supply systems (Ref. AERB Safety Code, AERB/SC/D, 1989 and the design safety guide on Application of Single Failure Criteria, AERB/SG/D-2).

3.10 Associated Circuits

3.10.1 Power circuit, control circuit or instrumentation circuit (e.g. power cable to turbine lube oil pump getting supply from safety-related bus may not be having physical separation with other safety-related cables) can become associated with emergency electric power supply systems in one or more of the following ways:

(a) electrical connection to an emergency electric power supply systems without the use of an isolation device;

(b) electrical connection to an associated power supply system without the use of an isolation device;

(c) proximity to emergency electric power supply systems and equipment without having the required physical separation or barriers;

(d) proximity to associated circuits and equipment without having the required physical separation or barriers; and

(e) sharing an emergency electric power supply system or associated signal source without the use of an isolation device.

3.10.2 The associated circuits shall comply with one of the following requirements:

(a) they shall be uniquely identified as such or as emergency electric power supply systems. They shall remain with the same group of emergency electric power supply systems to which they were originally associated or be physically separated from the same as those emergency electric power system circuits with which they are associated. They shall be subjected to the requirements placed on emergency electric power supply systems unless it can be demonstrated by analysis or testing that the absence of such requirements cannot degrade the emergency electric power supply systems below an acceptable level; and

(b) they shall be in accordance with 3.10.2 (a) from the emergency electric power supply equipment to and including an isolation device. Beyond the isolation device, such a circuit is a non-emergency electric power supply system provided that it does not again become associated with an emergency electric power supply system.

3.10.3 Associated circuits, connected to the emergency electric power supply system without qualified isolation devices shall be subject to qualification requirements placed on emergency electric power supply system. Associated circuits need not be qualified for performance of function, since the function is not safety-related.

3.11 Equipment Qualification

3.11.1 Equipment used in emergency electric power supply systems shall be capable of fulfilling its performance requirements under DBEs (earthquake, LOCA etc.) for the design life of equipment.

3.11.2 As per provisions of IEEE-323, the equipment shall be qualified by confirming that it will meet or exceed its design basis performance requirements while being subjected to environmental conditions existing at the time of need. The conditions include expected variations for normal operation during and after DBE. The qualification programme shall set out performance acceptable criteria and verify by testing and analysis that the equipment is acceptable when subjected to the effects of environmental conditions that may occur during the design life of the equipment. Equipment qualification should be done as per agreed procedures, which are prepared based on applicable codes and standards (Ref. AERB design safety guide on Protection against Internally Generated Missiles and Associated Environmental Conditions, AERB/SG/D-3).

3.11.3 Principles of Qualification

3.11.3.1 Qualification may be carried out in several ways, either individually or, where necessary, in combination.

3.11.3.2 Type testing of actual equipment performance by the manufacturer according to recognised standards using simulated service conditions, is a method of qualifying equipment. This method may be used for qualifying the greater portion of equipment in emergency electric power supply systems. Where manufacturers type tests are insufficient for NPP, additional tests shall be performed to demonstrate that the equipment will perform as required in the specified environment.

3.11.3.3 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.

3.11.3.4 Qualification by analysis shall include justification of methods, theories and assumptions made.

3.11.3.5 Analysis method is not recommended unless the validity of mathematical models has been justified by experimental data or operating experience.

3.11.3.6 Equipment used in emergency electric power supply systems (e.g. DG set, batteries) shall be capable of fulfilling its performance requirements if required, during and after a seismic event.

3.12 Single Failure Criterion

3.12.1 AERB Code of Practice on Design for Safety in Pressurised Heavy Water Based Nuclear Power Plants (AERB/SC/D, 1989) and the design safety guide on Application of Single Failure Criteria (AERB/SG/D-2) establish the basis for applying single failure criterion to emergency electric power supply systems. Conformance to these requirements should be ensured during design.

3.13 Support System for Emergency Electric Power Supply System

3.13.1 Each DG set shall have dedicated, independent and separate day tank for fuel and an associated fuel supply system from day tank to each DG set. Dedicated and separate bulk storage tanks with associated transfer system can be provided for each group. Alternatively, common storage tank with associated transfer system can be provided for all groups in which case, at least two tanks should be provided.

3.13.2 The day tank shall have adequate fuel capacity to supply the maximum required loads for a specified period. Capacity of bulk storage of fuel shall be sufficient to permit simultaneous operation of loads important to safety following DBE that consumes the maximum energy. The amount of bulk storage of fuel shall be based on analysis of the time required to replenish the storage from off-site. However, the minimum storage at site should be for 7 days.

3.13.3 Periodic fuel evaluation programme for DG sets should be established at site to identify degradation of fuel and to initiate appropriate action.

3.13.4 Ventilation system, compressed air for DG starting systems, control supply, fire detection and suppression systems for DG set(s) associated with each group shall be electrically and physically independent from similar systems for DG set(s) in the redundant group.

3.13.5 Areas having equipment belonging to one group of emergency electric power supply systems shall be provided with emergency lighting from the same group. Critical operating areas like control room etc. shall have emergency lighting system from both groups. In addition, emergency lighting having in-built energy source shall be provided in the control room. Part of this emergency lighting should supply from class II or I source.

3.14 Protection Against Physical Damages

To meet single failure criterion, emergency electric power supply systems shall be sufficiently protected against hazards that may result from DBE. Hazards that could affect emergency electric power supply systems include effects of fire, failure or mal-operation of fluid systems and failure of mechanical or structural components (Ref. AERB design safety guide on Protection against Internally Generated Missiles and Associated Environmental Conditions; AERB/SG/D-3). In addition, design of emergency electric power supply systems shall take account of the following:

(a) circuits or portions of emergency electric power supply systems shall be located or protected such that failure of related mechanical systems, structures and equipment of one group cannot disable circuits, structures or equipment of the other redundant group essential to perform the safety task. These failures can occur within the boundary of emergency electric power supply systems as well as that powered by emergency electric power supply systems. The effects of high energy pipe whip due to feed water lines and steam lines, jet impingement, radiation, pressurisation, elevated temperature, humidity and potential generation of missiles resulting from failure of rotating equipment shall be considered during design stage. (Ref. AERB design safety guide on Protection against Internally Generated Missiles and Associated Environmental Conditions; AERB/SG/D-3); and

(b) equipment used in emergency electric power supply systems should be either located in such areas where there is no potential for internal flooding or protected by suitable means to prevent effects of internal flooding.

3.15 Control of Access

Suitable provisions should be made for control of access to equipment of emergency electric power supply systems and support systems as envisaged in AERB Design Safety Code, AERB/SC/D, 1989.

3.16 Electrical Penetration

3.16.1 Electrical penetration assemblies shall be provided in reactor containment structures for conductors of circuits originating from emergency electric power supply systems and electrical auxiliary system. These electrical penetrations shall be rated and qualified for expected service and environmental conditions that include cumulative radiation effects expected throughout their design life and expected DBE.

3.16.2 The portion of containment penetrations coming in contact with live parts shall have a continuous service voltage rating greater than or equal to the voltage of the systems of which the conductors are a part. They shall also have power frequency and impulse voltage withstand capability as applicable greater than or equal to that specified transient voltage for associated cable. Conductors/cables/ penetrations shall be sized to carry the current taking into account the voltage variations and short circuits as well as demands from loads under DBE, without exceeding allowable conductor temperatures or degradation of pressure boundaries of the assemblies. The penetration assembly shall be designed to withstand without loss of mechanical integrity, overload condition together with a single random failure in the circuit of overload protection devices.

3.16.3 Separate penetration assemblies should be provided for each group, and they shall meet independence criteria as the cables to which they are connected.

3.17 Fire Protection

The design of emergency electric power supply systems shall take into account the fire protection requirements specified in design safety guide on Fire Protection (AERB/SG/D-4).

3.18 Station Blackout (SBO)

3.18.1 During station blackout, all class IV and class III power supplies are not available. Class II and class I power supplies continue to be available as long as station batteries are capable of providing the required input. The station blackout probability and the duration of station blackout depends on various factors. Some of the important factors are brought out.

3.18.2 Factors influencing total failure of class IV power supply are:

(a) plant grid interactions;

(b) grid disturbances leading to cascade tripping of transmission lines;

(c) non-availability of start-up transformer when unit is not in service (applied to units, where generator circuit breakers are not provided);

(d) switchyard faults and/or faults in class-IV system;

(e) weather induced disturbances; and

(f) earthquake with magnitude greater than that considered in the design of transmission system.

3.18.3 Factors influencing total failure of class III power supply are:

(a) number of DG sets provided for each unit and the number of DG sets required to meet safety loads of the unit;

(b) reliability of DG sets to start on demand and accept loads;

(c) degree of independence between redundant DG sets provided;

(d) expected frequency of loss of class IV power; and

(e) faults in class III system.

3.18.4 The station blackout 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. Station blackout 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 of alternate AC supply source and the degree of control the stations have on such alternate 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 power; and

(g) meantime to repair failed DG sets.

Considering the above factors the expected station blackout duration is arrived for each station. For details of methodology to calculate the station blackout duration refer IAEA TEC.DOC-332.

3.18.5 Subsequently, considering the expected station blackout duration, safety analysis is performed for the plant, to check the adequacy of the design. If required, additional provisions may have to be made to ensure safety of the plant during the expected station blackout duration. (Ref. AERB design safety guide on Design Basis Events, AERB/SG/D-5)

3.19 Classes of Emergency Electric Power Supply Systems

3.19.1 Basis

Emergency electric power supply systems are classified into 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.

3.19.2 Class III Power Supply System

AC power supply system normally fed from class IV power supply system and backed up by emergency DGs is called class III power supply system. The loads connected to this power supply system shall be capable of tolerating short time power supply interruption (say 2-3 minutes) and this should be considered in the plant safety analysis.

3.19.3 Class II Power Supply System

Class II AC supply system derives the supply normally through DC-AC inverter fed by a AC-DC converter connected to a class III AC system. This system is backed up with battery and providing an uninterrupted AC supply to the connected loads. The AC-DC converter normally supplies load through inverter and also charges the battery which provides input to the inverter in the event of class III failure/transients*.

3.19.4 Class I Power Supply System

DC supply system is normally supplied from AC power system of the emergency electric power supply systems through AC-DC converter (rectifier). In case of failure of AC power to rectifier the battery continues to supply to the loads without interruption.

3.20 Control and Instrumentation Power Supply

The input to control and instrumentation power supply are derived from emergency electric power supply systems. These power sources are generally provided with battery backup. Details of this power supplies are covered in AERB safety guides on Safety Critical Systems (AERB/SG/D-10) and Safety Related Instrumentation and Control (AERB/SG/D-20).

3.21 Safety and Seismic Classification

Safety classification and seismic categorisation of components, structures and systems of emergency electric power supply systems shall conform to AERB safety guide on Safety Classification and Seismic Categorisation (AERB/SG/D-1).

* During the failure of DC-AC inverter, depending on the equipment provided, a short power supply interruption of about 750 ms is expected to the loads connected to class II bus.

3.22 Accidents and Combination of Events

Applicable DBEs for emergency electric power supply system shall be identified as per the design safety guide on Design Basis Events (AERB/SG/D-5) and their consequences analysed.

3.23 Earthing

Earthing shall conform to the provisions of Indian Electricity Rules, 1956 and IS-3043.

3.24 Lightning Protection

Lightning protection should conform to applicable code of practice, IS-2309.

3.25 Surge Voltage Protection

Over-voltage surges can be caused by lightning strikes, electrical faults or switching phenomena. If the surge potential exceeds allowable voltage, surge suppressors or arrestors shall be provided for emergency electric power supply system and their instrumentation as per applicable codes.

3.26 Lighting

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

3.27 Residual Life Assessment and Condition Monitoring

Provisions may be made to monitor critical parameters like winding temperature, ambient temperature, insulation dielectric properties (insulation resistance, polarisation 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)

4. DESIGN REQUIREMENTS OF EMERGENCY ELECTRIC POWER SUPPLY SYSTEMS

4.1 General

4.1.1 This section covers design requirement of the following power supplies and associated distribution systems used as a part of emergency electric power supply system.

- Class III AC power supplies;
- Class II AC power supplies;
- AC distribution system for class II and class III systems;
- Class I DC power supplies; and
- DC distribution systems for class I system.

4.1.2 The equipment of emergency electric power supply system are required to provide electric power supply to equipment and systems performing the safety functions under various DBE. This puts stringent requirements in the selection, design, qualification, operation and maintenance of emergency electric power supply systems. Following sections deal with selection and design of these systems.

4.1.3 Equipment of emergency electric power supply system shall be capable of performing its intended function during and subsequent to specified design basis earthquake conditions.

4.2 Class III AC Power Supplies

4.2.1 Class III AC system of each group consists of:

(a) AC standby power supply sources; and

(b) AC distribution system.

4.2.2 The AC standby power supply sources shall be available following the loss of the normal power supply within a time consistent with the requirements of the safety functions under DBEs.

4.2.3 The AC standby power supply source consists of a prime mover, alternator and excitation system complete with all auxiliaries. The AC standby power supply source of each redundant load group shall have dedicated, separate and independent stored energy supplies (e.g. compressed air for starting, stored fuel, lubricating oil etc.), generator excitation system, control system, protective systems and auxiliary power supplies etc.

4.2.6 Following requirements shall be applicable for Diesel Generator (DG) sets used as AC standby power supply sources:

4.2.6.1 DG sets 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 normal power supply, and during and after DBE.

4.2.6.2 Number of times the DG is called upon to start and the time period it is required to operate continuously during life of the plant depends on reliability of the normal power supply, frequency of DG test starts and station Technical Specification requirements etc.

4.2.6.3 The above details form part of the design basis for qualification of DG sets for a given standby application. Conditions requiring starting of DG sets should be covered in design basis report.

4.2.7 The DG set along with its accessories and auxiliaries shall be capable of performing the intended functions under the following:

- under applicable conditions (ambient temperature and pressure, humidity, salt/sand contaminants in combustion air, cooling water quality etc.) that are expected at the place of installation;
- when using fuel of specified quality;
- during and subsequent to specified design basis earthquake conditions;
- when subjected to specified load profiles expected under various operating conditions without exceeding acceptable voltage and frequency limits; and
- even after operating for a specified period at no load or reduced load.

4.2.8 DG set shall be capable of starting, accelerating and accepting design load within a time acceptable for the intended safety function it performs. The DG set shall be capable of starting:

- from normal standby condition;
- with cooling not available for a time equivalent to that required to bring cooling equipment into service using energy from the DG set itself; and
- on a restart with an initial engine temperature equal to the stabilised full load engine temperature.

4.2.9 DG set shall be capable of maintaining output voltage wave form distortion, voltage imbalance and frequency at the generator terminals within a range that will not degrade the performance of loads connected to the generator below acceptable limits. Typical examples are given below:

Steady-state voltage variation:	$\pm$ 6%
Steady-state frequency variation:	$\pm$ 3%
Transient voltage variation on application or removal of the largest single step load:	$\pm$ 20%
Transient frequency variation on	
(a) application or removal of largest single step load :	$\pm$ 5%
(b) load throw off:	+ 75% of difference between rated speed and over speed setting of DG.
(c) Expected recovery time for the above transient conditions:	60% of time interval between two successive load restorations.

Loads supplied by DG sets shall be designed to safely withstand the expected transient voltage and frequency variations during loading of DG sets.

4.2.10 DG set shall have appropriate overloading capability for a specified duration which should be at least 10% over-load for a period of one hour in every 12 hours of operation. DG sets may be utilised to the limit of their power capabilities, including this overloading capability as defined provided the performance of DG set is not affected.

4.2.11 The following precautions should be taken when DG sets are expected to operate at light and no load conditions:

(a) when 4 h operation at 30% or less of the continuous rating have been accumulated without at least 0.5 h operation above 50% of the continuous rating, the DG set shall be operated at a load of at least 50% of the continuous rating for a minimum of 0.5 h;

(b) operating at 30% or greater continuous rating shall be restricted to the manufacturer's recommendations; and

(c) irrespective of the recommendations in (a) and (b) above, light load and no load operating duration and load parameters should be established in consultation with DG manufacturer:

4.2.12 Mechanical, electrical and instrumentation and control design features shall be considered in the design of DG set as covered in the applicable clauses of IEEE-387.

4.2.13 DG set reliability should be commensurate with the reliability figure assumed in the overall system safety analysis.

4.2.14 Provisions shall be made in the design to control DG set from control room as well as from the local DG control panel. Local/remote and auto/manual selection switch for DG set should be located in the local panel and control room respectively. An alarm should be provided in the control room to alert the operator in case of change in the status of selection switch.

4.2.15 DG set shall be designed to provide remote and local surveillance and to indicate abnormality, pre-trip, or trip conditions as envisaged in the applicable clauses of IEEE-387.

4.2.16 Protections and controls for a DG set shall be provided as per applicable clauses of IEEE-387.

4.3 Class II Uninterrupted Power Supplies

4.3.1 Some of the safety-related loads require Uninterrupted Power Supply (UPS) so as not to intercept the safety function, to which they supply power. UPS system provides reliable, regulated and filtered uninterrupted power to loads connected and also minimises the effects of electrical power supply disturbances and variations. UPS system continues to supply required power from DC power source consisting of a battery, in case of disturbances or loss of class III AC power supply.

4.3.2 Where a provision exists to connect any class II bus to the redundant class II bus, transfer of supply from available class II to redundant class II bus shall be carried out manually without jeopardising the safety functions that it is serving.

4.3.3 UPS system consists of:

- AC to DC converter (static or dynamic)
- DC to AC inverter (static or dynamic)
- battery backup

AC to DC converter converts input class III AC power supply to DC power and this supply is used as input to the DC to AC inverter and also for charging the battery.

The inverter converts DC power into AC power that will be further distributed to different safety loads.

During class III power interruptions, the battery will continue to feed the loads through inverter.

4.3.4 UPS System shall be capable of performing its intended functions:

- under ambient conditions (e.g. temperature, humidity, etc.) expected at the place of installation, and
- during and subsequent to specified design basis earthquake conditions.

4.3.5 In selecting UPS systems, the types and characteristics of the loads being supplied should be carefully considered. The following factors should be considered while selecting UPS systems:

- 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; and
- consideration should also be given to selection of fault clearing devices to compensate for lack of capability to supply high short circuit current.

4.3.6 The following load data may be used in sizing of an UPS system:

(a) total steady state load;

(b) load power factor;

(c) continuous or short duration load;

(d) inrush current requirement of load; and

(e) load linearity.

4.3.7 The following examples describe the usual characteristics and limitations for power sources of UPS systems:

- the input source is usually 415V, 3 phase, 50 Hz AC supply. Steady state voltage variation shall be within ± 6%, frequency variations shall be within ± 3% and unbalance voltage within 3%;
- the source may be solidly grounded, resistance grounded or ungrounded;
- the total harmonic injection into the source shall be within acceptable limits for equipment connected to Class III bus;
- UPS shall be capable of withstanding over-voltage transients and under-voltage transients including complete loss of voltage,

- class III system fault level shall be considered in the design of UPS; and
- output is usually 415V, 3 phase, 50 Hz AC supply. Steady state voltage variation shall be within ± 6%, frequency variations shall be within ± 3%, unbalance voltage within 3% and the total harmonic distortion shall be < 5%.

However, steady state and transient voltage and frequency variations shall be within the capability of loads connected to class II system.

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

- the DC source is usually ungrounded with provisions for ground detection;
- for UPS units in which DC source is not dedicated to the inverter(s) the magnitude of ripple voltage shall not exceed values permitted for equipment connected to DC bus;
- if UPS is required to operate without the battery during battery maintenance, then the converter and inverter characteristics need to be coordinated; and
- equipment connected to DC system shall be capable of withstanding expected over-voltage.

4.3.9 UPS availability shall be commensurate with the reliability requirement of safety loads it is supplying. The total time class II is 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.

4.3.10 UPS system selection and procurement generally conform to applicable clauses of IEEE-944 and IEC-146.

4.4 AC Distribution System for Class III and Class II Systems

4.4.1 The buses and cables of emergency electric power supply system shall be selected, rated and qualified for service considering normal operation as well as fault conditions. They shall also qualify for environmental conditions taking into account cumulative radiation effects, if applicable, and thermal ageing expected throughout their design life including DBE. They shall also be sufficiently fire retardant to prevent propagation of fires. Special attention shall 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.

4.4.2 Buses and cables shall 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.

4.4.3 Buses and cables shall 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 shall 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 shall 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 considered in the AERB safety guide on Fire Protection (AERB/SG/D-4).

4.4.4 Buses and bus-duct supports shall be designed to withstand mechanical loads imposed on them.

4.4.5 The following aspects should be considered during design, to limit the electromagnetic interference from power circuits within acceptable values:

(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.

For further details refer applicable clauses of IEEE-1143 "On Shielding Practices for Low Voltage Cables"

4.4.6 Cable trays and their supports shall be designed to withstand mechanical loads imposed by cables and associated fittings. Cable trays shall be permanently identified with their respective emergency electric power supply system groups. Each cable shall be given sufficient identification during installation to ensure installation in the proper tray; as a minimum, cables shall be permanently identified at each end after installation.

4.4.7 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.

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

4.4.9 Control and instrumentation cables, medium voltage power cables e.g. 650 V or less and high voltage power cables e.g. 33 kV or less shall be placed in separate cable trays, with adequate separation.

4.4.10 Buses, cables, wires and switchboards of one redundant emergency electric power supply system group shall be physically separated and electrically isolated from the other redundant group distribution system. Separation is necessary for ensuring that a fault in one group does not propagate to others. Faults of particular concern are fires initiated either by external causes or by faults internal to electrical equipment (over-currents causing electrical insulation to melt). Such propagation can result from either close proximity or physical routes that link together the circuitry of redundant groups e.g. flammable structures or cables and wiring that run between groups. Such cabling/wiring links can be of two types:

(a) actual cabling/wiring connections built into the design of a system; and

(b) cabling/wiring connections of other circuits, either in systems important to safety or systems not important to safety that are routed through more than one emergency electric power supply system group.

The requirements to prevent fire propagation are considered in AERB safety guide on Fire Protection (AERB/SG/D-4). The requirements for preventing propagation of the effects of over-currents and short circuits shall be met by physical separation between cables of different groups and by incorporation of isolation devices on all cables that are likely to electrically connect redundant groups together. Separation distances between circuits requiring independence should take into account the potential hazards within the area and shall be as per relevant standards. Alternatively, analysis or tests may be used to justify adequacy of physical separation.

4.4.11 Fire Survival (FS) cables shall be used for safety circuits where redundancy of safety circuits cannot be ensured due to various constraints. Use of Fire Retardant Low Smoke (FRLS) cables in general shall be considered to minimise the hazards due to fire.

4.4.12 It may be considered necessary in special situations to operate safety system equipment in overloaded conditions to ensure fulfillment 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 shall 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 recognised 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.

4.4.13 The installation shall conform to Indian Electricity Rules, 1956.

4.4.14 AC supply to auxiliary devices required for operation of equipment associated with a load group shall 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.

4.4.15 Any power/control cables of emergency electric power supply systems located in safety class structure and systems located in non safety class structure shall be provided with qualified safety class isolating devices located in the safety class structure (Ref. IEEE-308). Otherwise the non-safety class cables should be run in a segregated manner so as not to affect the safety class circuits due to its failure.

4.4.16 Protective devices shall be properly sized, calibrated and coordinated so that only the faulty part of emergency electric power supply system is isolated without affecting the function of healthy part.

4.5 Class I DC Power Supply

4.5.1 General

4.5.1.1 Class I DC system of each group shall consist of :

- battery;
- AC-DC converter; and
- associated DC distribution system.

4.5.1.2 In case of loss of AC power supply, certain DC operated safety-related systems and components like circuit breakers, relays, solenoids and inverters require uninterrupted power.

4.5.1.3 In each safety-related group, DC source may be a common battery for both power and control and instrumentation or two separate batteries. Additional safety-related batteries are required for special services such as for starting DG sets.

4.5.1.4 In case non-safety DC loads are to be connected to safety DC buses, the requirements of independence criteria as given in 3.8 of this guide shall be applied for such connections.

4.5.1.5 The battery and charger(s) are normally connected to the DC distribution bus in parallel. The charger, in addition to charging/float charging the battery, will carry normal continuous load. The charger output voltage characteristics are such that the battery will supply all momentary loads in excess of the charger capacity.

4.5.2 Batteries

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

- loss of AC power to the charger; or
- charger failure; or
- removal of the charger from service for maintenance.

4.5.2.2 A separate battery shall be provided for each redundant safety group in each unit to provide the required independence between redundant groups as mentioned in 3.8 of this guide. The rating and capacity should be calculated as given in section 4.5.2.7 of this guide.

4.5.2.3 In each redundant group, at least one battery charger and main distribution panel should be provided for each battery system. Standby battery charger can be provided to increase the operational flexibility and availability.

4.5.2.4 The connected load governs the maximum and minimum operating voltage limits of the battery. The voltage limits for breaker control circuits and relays as given in IS-13118, IS-13947 and IS-3231 should be followed.

4.5.2.5 The time period for which the battery shall be required to supply the loads depends upon the time interval necessary to restore AC power (either from on-site AC generator or off-site power source whichever is earlier) to the battery charger, following a loss of off-site power. For example, back-up duration of 30 min for power battery and 1 h for control batteries is generally provided to take into account operator intervention. Under station blackout condition, capacities of class I power supplies should be integrated with demands imposed on them during SBO as established by the analysis as detailed in 3.18. To extend the availability of class I power supplies during SBO condition predetermined load shedding may also be incorporated in operating procedures.

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

4.5.2.7 The capacity of battery shall be decided based on the following:

(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.

4.5.2.8 A DC 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.

4.5.2.9 Batteries shall perform their intended function during and subsequent to specified design basis earthquake conditions.

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

4.5.3 Battery Charger

4.5.3.1 Battery charger should be sized keeping an adequate design margin and IEEE 946 should be followed while sizing the battery charger.

4.5.3.2 In each group, at least one battery bank and associated charger should be provided.

4.5.3.3 The battery charger shall be capable of performing its intended functions under the ambient conditions (e.g. temperature, humidity, etc.) expected at the place of installation and during and subsequent to specified design basis earthquake conditions.

4.5.3.4 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. Permissible current harmonics injected into the system should not cross the limits given in the applicable clauses of IEEE-519 or equivalent.

4.5.3.5 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 shall 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 as detailed in 4.6.18

4.5.3.6 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.

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

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

4.6 DC Distribution System for Class I Systems

4.6.1 The distribution system shall consist of all equipment in the distribution circuit from its incoming supply isolation device and up to the loads.

4.6.2 Each distribution circuit shall be capable of transmitting sufficient energy to start and operate all required loads in that circuit.

4.6.3 Distribution circuits to redundant equipment shall be physically and electrically independent of each other as mentioned in 3.8 of this guide. There shall 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.

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

4.6.5 Any power/control cables between emergency electric power supply systems located in safety class structure and systems located in non-safety class structure shall 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.

4.6.6 Protective devices shall be properly sized, calibrated and coordinated so that only the faulty part of the emergency electric power supply system is isolated without affecting the function of the healthy part.

4.6.7 Each battery and battery charger of one group should be connected to one main distribution panel to which loads of that group are connected.

4.6.8 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 shall activate alarm in the control room.

4.6.9 The buses in main distribution panel should be insulated to minimise 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.

4.6.10 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.

4.6.11 The main protective device should coordinate with the remaining downstream protective devices. All protective devices should have a voltage rating consistent with the maximum system operating voltage. These protective devices should also have an interrupting capacity that exceeds the maximum short circuit current available.

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

4.6.13 Typical configurations for DC supply system along with distribution system and battery charger connections are given in Figures 3A and 3B.

4.6.14 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.

4.6.15 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.

4.6.16 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-energised, if not suppressed.

4.6.17 Design features of each DC system should provide an effective and safe means to perform a periodical capacity discharge test on each battery. Figures 3A and 3B show the typical arrangement provided for testing the batteries.

4.6.18 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 4.5.2.8 and 4.5.3.8. 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 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.

4.6.19 The total short circuit current available (the required interrupting capacity for feeder breakers/fuses) is the sum of that delivered by the battery, charger and motors that are connected in the system.

The short circuit current delivered by a battery depends on the total resistance of short circuit path. Normally, short-circuit current is expected to be 10 times of the 1 minute ampere rating at the end of battery discharge.

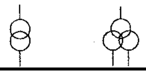
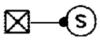
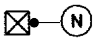
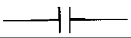
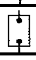
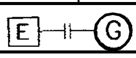
The maximum current that a charger will deliver into a short-circuit is determined by its current limit circuit and its setting is adjustable in most of the chargers and may vary from one manufacturer to another. The maximum current that a charger delivers on short circuit does not typically exceed 150% of the charger ampere rating.

DC motors, if operating will contribute to total fault current. However, it is insignificant for motor sizes used in emergency electric power supply systems.

4.6.20 The recommended instrumentation, controls, and alarms for class I DC system are given in the Fig. 3A and 3B. 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 remote location.

4.6.21 The installation shall conform to Indian Electricity Rules, 1956.

4.6.22 Provision shall be made in design for carrying out commissioning, surveillance, testing, in-service inspection and maintenance of emergency electric system equipment. The requirements of safety guide on Design for In-service Inspection (AERB/SG/D-17) shall be met.

LEGEND FOR FIGURES	
	Plant Generator
	Transformer
	Circuit Breaker On
	Circuit Breaker Off
 GCB	Generator Circuit Breaker
	AC-DC Converter (Rectifier)
	DC-AC Converter (Inverter)
	Battery
	Safety Load with Safety Input Terminal upto Dot
	Non Safety Load with Safety Input Terminal upto Dot
GT	Generator Transformer
SUT	Start Up Transformer
UAT	Unit Auxiliary Transformer
	Fuse
	Under Voltage Relay
	Earth Leakage/Ground Fault Relay
	Voltmeter
	Ammeter
	Alarm Connected in Main Control Room
MCR	Main Control Room
	Switching Device
	DC Shunt
	Stand by DG Set

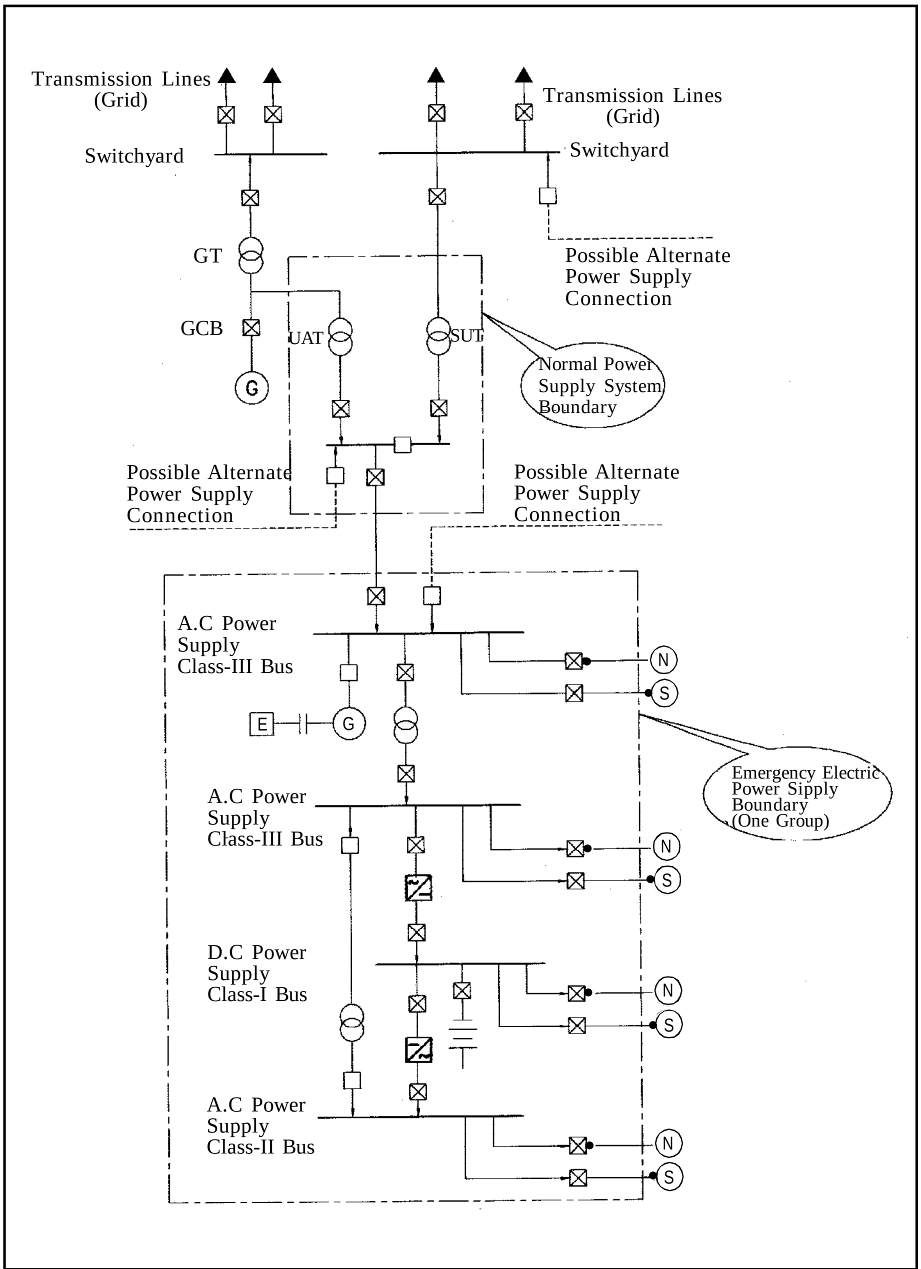


FIGURE 1A : SCHEMATIC REPRESENTATION OF DIFFERENT CLASSES OF EMERGENCY ELECTRIC POWER SUPPLY SYSTEMS WITH THEIR BOUNDARIES

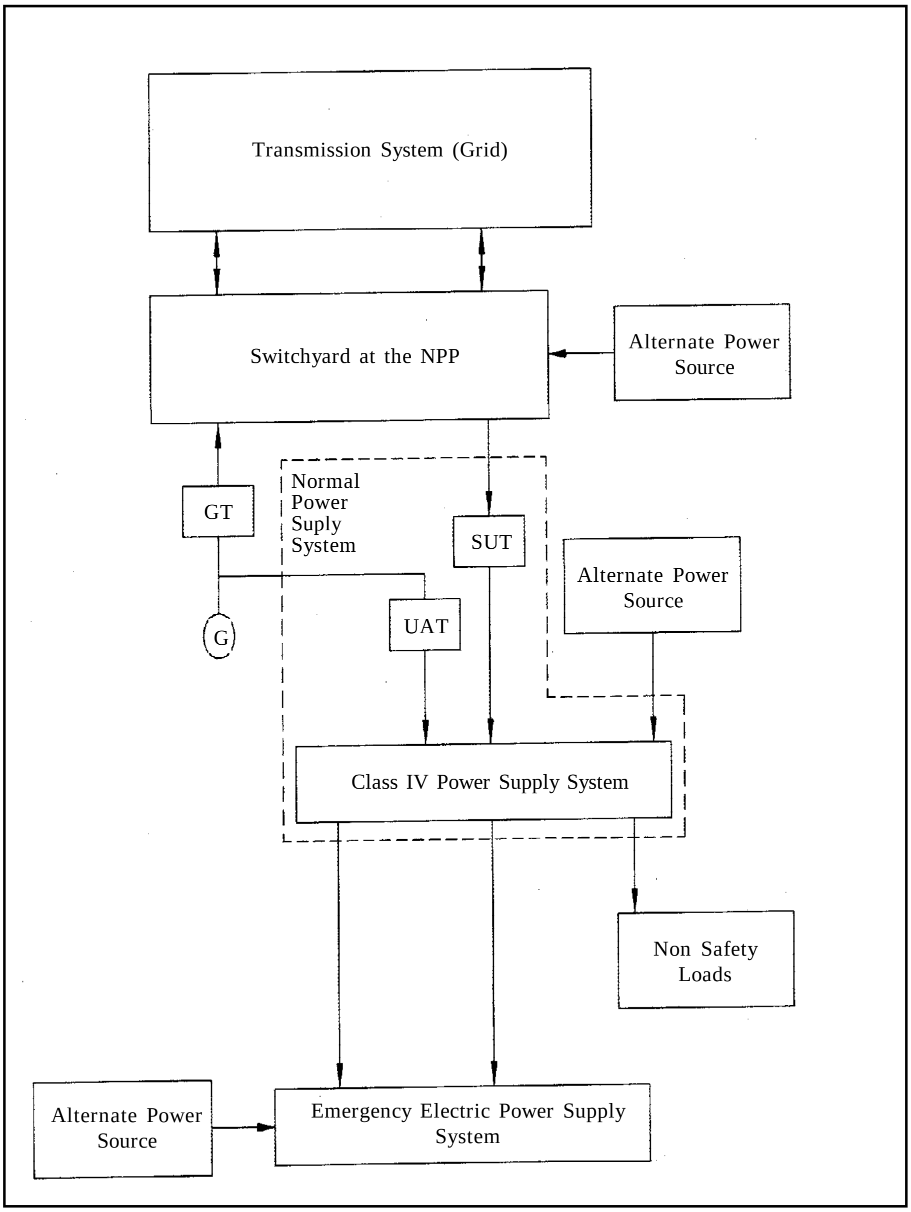


FIGURE 1B : ARRANGEMENT OF CONNECTION BETWEEN NORMAL POWER SUPPLY AND EMERGENCY ELECTRIC POWER SUPPLY

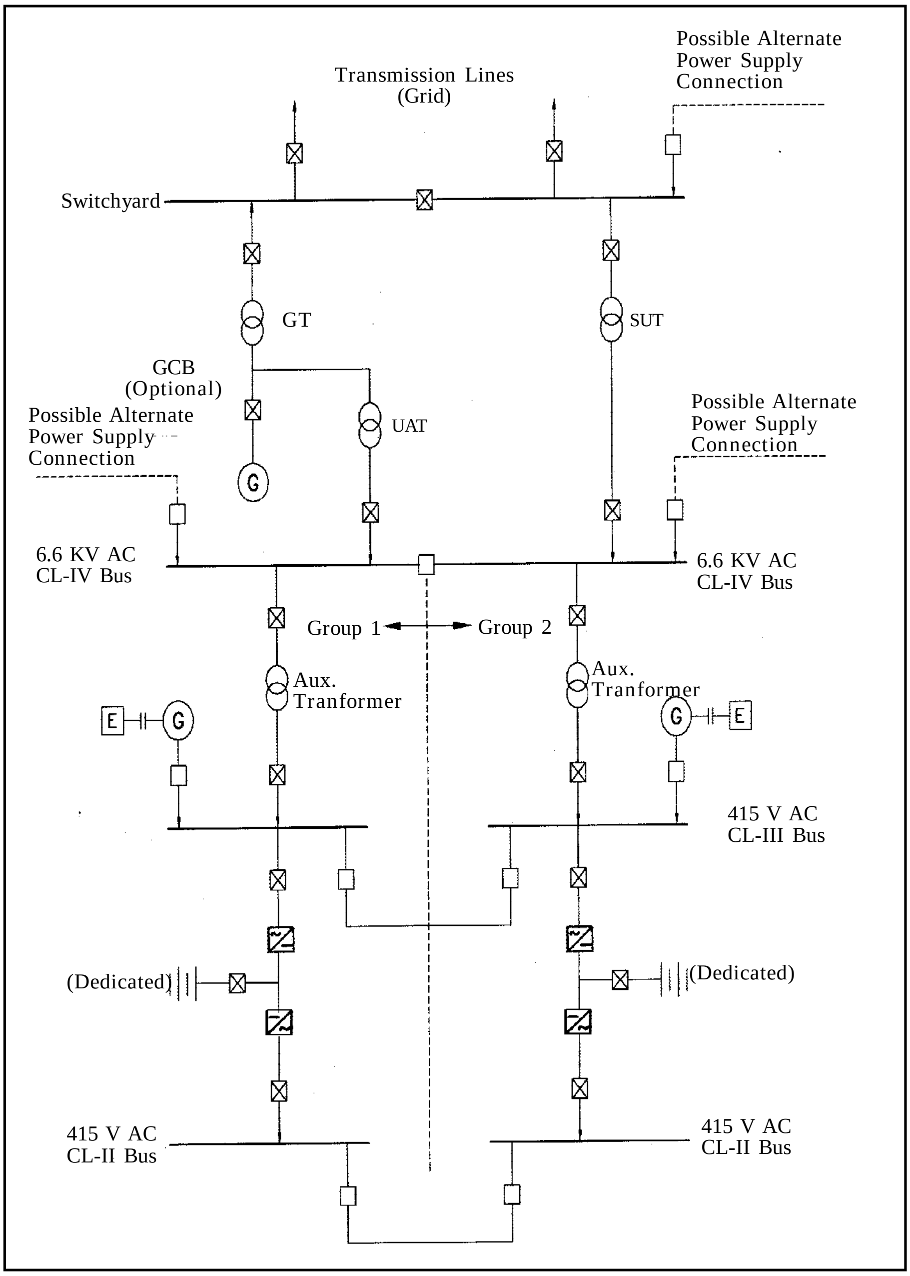


FIGURE 2A : TYPICAL AC POWER SUPPLY ARRANGEMENT AND ALTERNATE POWER SUPPLY CONNECTIONS (OPTION - 1)

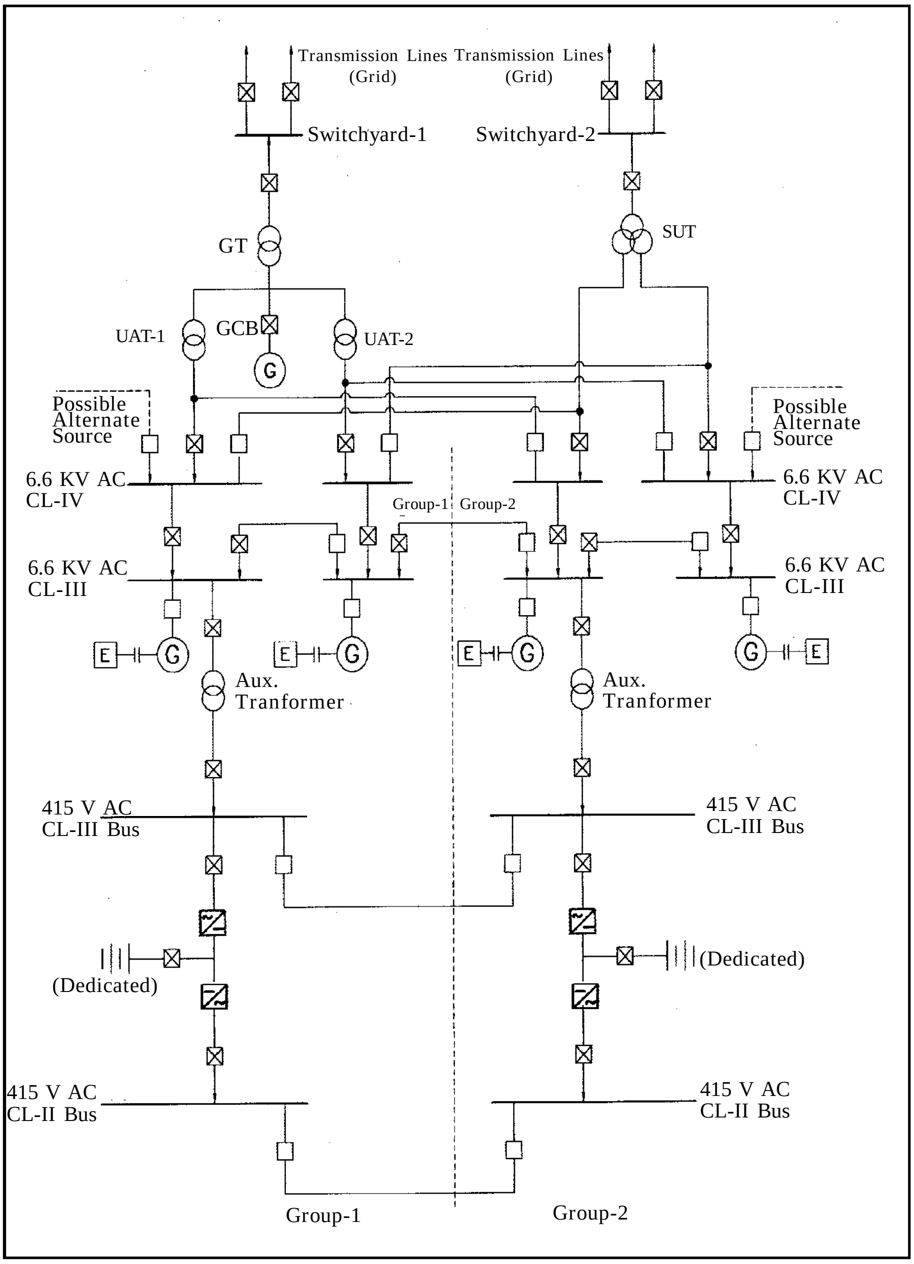


FIGURE 2B : TYPICAL AC POWER SUPPLY ARRANGEMENT AND ALTERNATE POWER SUPPLY CONNECTIONS (OPTION - 2)

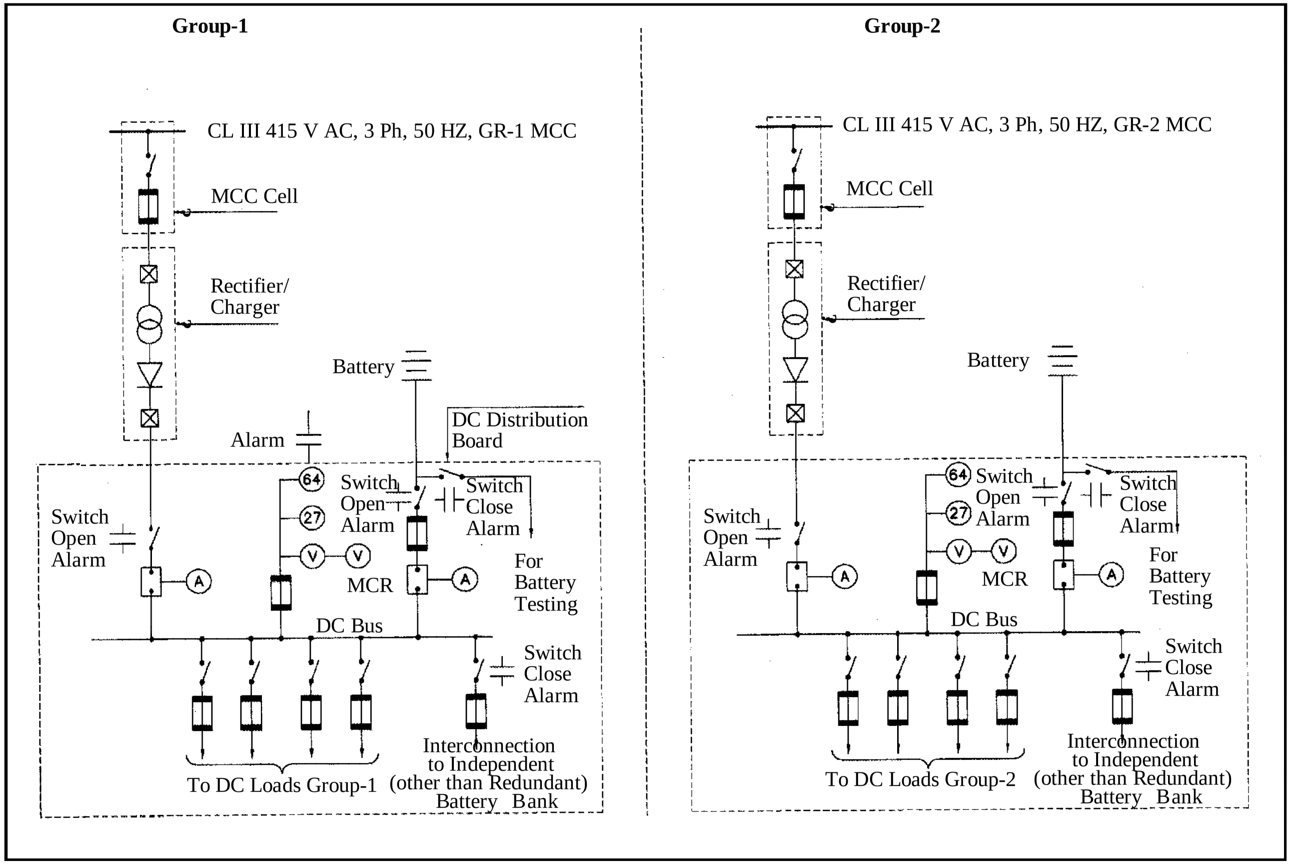


FIGURE 3A : TYPICAL SCHEME FOR DC SYSTEM

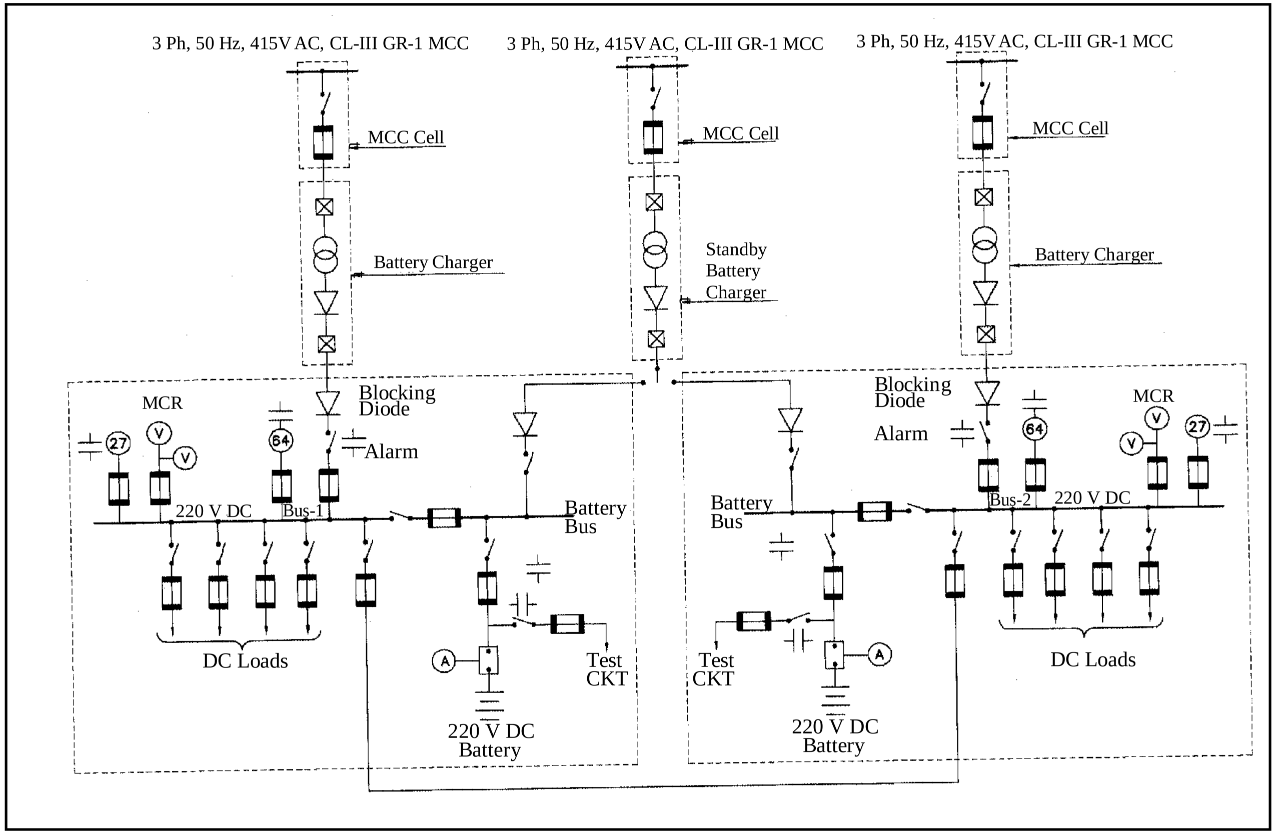


FIGURE 3B : TYPICAL SCHEME FOR 220 V DC SYSTEM FOR ONE GROUP

REFERENCES

I. ATOMIC ENERGY REGULATORY BOARD (AERB) CODES AND GUIDES

1. AERB, " Code of Practice on Design for Safety in Pressurised Heavy Water based Nuclear Power Plants" (AERB/SC/D, 1989)

2. AERB, "Safety Guide on Commissioning of Nuclear Power Plants" (AERB/SG/O-4, 1998)

3. AERB, "Safety Guide on Quality Assurance during Operation of Nuclear Power Plants", (AERB/SG/QA-5, 1993)

4. AERB, "Standard for Fire Protection Systems of Nuclear Facilities" (AERB/S/Fire-1996)

5. AERB, "Factories Rules", 1998

II INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS (IEEE) STANDARDS

1 IEEE, "Standard Criteria for Class IE Power Systems for Nuclear Power Generating Stations", (IEEE-308, 1991)

2. IEEE, "Standard for Qualifying Class IE Equipment" (IEEE-323, 1984)

3. IEEE, "Standard Criteria for Independence of Class IE Equipment and Circuits" (IEEE-384, 1992)

4. IEEE, "Standard Criteria for Diesel Generator Units Applied as Standby Power Supplies for Nuclear Power Generating Stations" (IEEE-387, 1984)

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III BUREAU OF INDIAN STANDARDS (IS)

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6. IS, "Standard for High Voltage Switch Gear and Control Gear" (IS-12729 1988)

7. IS, " Code of Practice for Interior Illumination" (IS-3646 - 1992)

IV INTERNATIONAL ATOMIC ENERGY AGENCY (IAEA) DOCUMENTS

1. IAEA, "Safety Aspects of Station Blackout at NPPs', TECDOC-332 (1985)

2. IAEA, "Safety Report Series No.15, "Implementation and Review of an NPP Ageing Management Programme", (1999)

V International Electro-technical Commission (IEC), Standard on "Semiconductor Converters", (IEC-146, 1974)

LIST OF PARTICIPANTS

WORKING GROUP

Dates of meeting	:	December 01, 1995 January 4 & 11, 1996 April 26, 1996 May 16 & 24, 1996 October 13 & 24, 1997 October 30, 1998 December 22, 1999

Members and invitee participating in the meetings:

Shri A. K. Gupta (Chairman)	:	Director, DCSEM
Shri G. K. De	:	AERB (Formerly)
Shri M. Ramaiah (partly)	:	NPCIL (Formerly)
Shri V. Raghavan (Partly)	:	NPCIL
Shri P. Lahiri	:	BARC
Shri Y. R. S. Prasad (partly)	:	NPCIL (Formerly)
Shri K. Jagannath	:	NPCIL
Shri S. N. Rao (Member-Secretary)	:	AERB
Shri W.A. Dharme (Invitee)	:	NPCIL
Shri M.K. Kannan (Invitee)	:	NPCIL

ADVISORY COMMITTEE ON CODES, GUIDES AND ASSOCIATED MANUALS FOR SAFETY IN DESIGN OF NUCLEAR POWER PLANTS (ACCGD)

Dates of meeting	:	October 4, 1996 April 28, 1999 June 3 & 4, 1999 December 27, 1999

Members and alternates participating in the meetings:

Shri S.B. Bhoje (Chairman)	:	Director, IGCAR
Shri S. Damodaran	:	NPCIL (Formerly)
Prof. N. Kannan Iyer	:	IIT, Bombay
Shri V.K. Mehra	:	BARC
Shri Umesh Chandra	:	BARC
Shri Deepak De	:	AERB
Shri S. Sankar	:	BARC
Shri C.N. Bapat	:	NPCIL
Shri S.A. Bhardwaj	:	NPCIL
Dr. S.K. Gupta	:	BARC
Shri R.S. Singh (Member-Secretary)	:	AERB (Upto 30.6.2000)
Shri S.A. Khan (Member-Secretary)	:	AERB

ADVISORY COMMITTEE ON NUCLEAR SAFETY (ACNS)

Dates of meeting	:	February 26, 2000 March 25, 2000

Members and alternates participating in the meetings:

Shri S.K. Mehta (Chairman)	:	Director RG, BARC (formerly)
Shri S.M.C. Pillai	:	Nagarjuna Power Corporation, Hyderabad.
Prof. U.N. Gaitonde	:	IIT, Bombay
Shri S.K. Goyal	:	BHEL, Hyderabad.
Shri Ch. Surendar	:	NPCIL (formerly)
Shri S.K. Sharma	:	BARC
Dr. V. Venkat Raj	:	BARC
Dr. U.C. Mishra	:	BARC (formerly)
Shri S.P. Singh	:	AERB (formerly)
Shri G.K. De	:	AERB (formerly)
Shri K. Srivasista (Member-Secretary)	:	AERB

PROVISIONAL LIST OF SAFETY CODE, GUIDES AND MANUAL ON DESIGN OF PRESSURISED HEAVY WATER REACTORS

Safety Series No.	Provisional Title
AERB/SC/D	Code of Practice on Design for Safety in Pressurised Heavy Water Based Nuclear Power Plants
AERB/SG/D-1	Safety Classification and Seismic Categorisation
AERB/SG/D-2	Application of Single Failure Criteria
AERB/SG/D-3	Protection Against Internally Generated Missiles and Associated Environmental Conditions
AERB/SG/D-4	Fire Protection in Pressurised Heavy Water Based Nuclear Power Plants
AERB/SG/D-5	Design Basis Events for Pressurised Heavy Water Reactor
AERB/SG/D-6	Fuel Design
AERB/SG/D-7	Core Reactivity Control in Pressurised Heavy Water Reactor
AERB/SG/D-8	Primary Heat Transport System
AERB/SG/D-9	Process Design
AERB/SG/D-10	Safety Critical System
AERB/SG/D-11	Emergency Electric Power Supply Systems for Pressurised Heavy Water Reactor
AERB/SG/D-12	Radiation Protection in Design
AERB/SG/D-13	Liquid and Solid Radwaste Management
AERB/SG/D-14	Control of Air-borne Radioactive Materials in Pressurised Heavy water Reactors
AERB/SG/D-15	Ultimate Heat Sink and Associated Systems in Pressurised Heavy Water Reactor

PROVISIONAL LIST OF SAFETY CODE, GUIDES AND MANUAL ON DESIGN OF PRESSURISED HEAVY WATER REACTORS (contd.)

Safety Series No.	Provisional Title
AERB/SG/D-16	Materials Selection and Properties
AERB/SG/D-17	Design for In-Service Inspection
AERB/SG/D-18	Loss of Coolant Accident Analysis for Pressurised Heavy Water Reactor
AERB/SG/D-19	Hydrogen Release and Mitigation Measures under Accident Conditions
AERB/SG/D-20	Safety Related Instrumentation and Control
AERB/SG/D-21	Containment System Design
AERB/SG/D-22	Vapour Suppression System for Pressurised Heavy Water Reactor
AERB/SG/D-23	Seismic Qualification
AERB/SG/D-24	Design of Fuel Handling and Storage Systems
AERB/SG/D-25	Computer based Safety Systems
AERB/SM/D-1	Decay Heat Load Calculations