Eskom	Standard	Technology

Title: **STANDBY POWER SYSTEMS TOPOLOGY AND AUTONOMY FOR ESKOM SITES**

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1. Introduction

Emergency standby power systems are designed to provide an alternate source of power if the normal source of power, most often the serving utility supply, should fail. Due to the physical nature of electrical networks, it is extremely vulnerable to environmental hazards and nowadays also to non-physical hazards like cyber-attacks that could cause significant damage to the well-being of a country.

Most applied technical standards makes provision for normal network emergencies that are generally restricted to a specific region and do not affect the network on a national basis. The impact of these incidents is localised and not significant. A national blackout on the other hand can be devastating and it can take days to restore the electricity network.

This document examines the vulnerability of electrical power systems to natural hazards, describes what equipment in critical facilities should be supplied by emergency power sources, how long the emergency power may be needed, the specific equipment needs of different types of critical facilities; and how emergency power can be supplied for as long as needed by the facility. It provides guidance on how to assess the power supply risks and vulnerabilities to the facility, identifying shortcomings of an emergency power system, and the importance of having realistic emergency management policies that address emergency power. It also discusses the advantages and limitations of redundant systems, the need for advanced planning of emergency power systems, potential pitfalls when sizing system components, such as fuel storage tanks, and provides examples of simple and complex installations. It emphasizes the need to apply a holistic approach to the design of a new emergency power system. In this document, a holistic approach means all elements of the design and operation of the emergency power system and the equipment using the power need to be considered, so that the facility will perform as intended under extreme design events, all in a cost effective manner.

2. Supporting clauses

2.1 Scope

2.1.1 Purpose

The purpose of the document is to identify the critical factors that should be considered when deciding on the best standby power system design parameters after the criticality of a site has been determined. It aims to provide standard system topologies and autonomies for different site criticalities and allow flexibility to improve on these measures in exceptional instances.

2.1.2 Applicability

This document shall apply throughout the Transmission Division, Distribution Division and Eskom Telecommunications of Eskom Holdings Limited Divisions.

2.2 Normative/informative references

Parties using this document shall apply the most recent edition of the documents listed in the following paragraphs.

2.2.1 Normative

[1] ISO 9001 Quality Management Systems.

[2] 240-56176852, Essential Power Supplies for Power Stations standard.

[3] 240-103059202, Capacity of Essential Power Supplies for Telecommunication, Protection and Telecontrol Equipment of the Transmission System.

[4] 240-112691204, Specification for Mobile Diesel Generator Systems.

[5] 240-51999453, Standard specification for valve-regulated lead-acid cells.

[6] 240-53114248, Specification for Thyristor and switch mode chargers, AC/DC to DC/AC converters and inverter/uninterruptible power supplies.

[7] 240-53114314 (DST_34-1299), Minimum Reliability and Capacity Requirements of Essential DC Power Supplies for various equipment at Distribution Sites.

[8] 240-56360034, Stationary vented lead acid batteries standard.

[9] 240-56360086, Stationary vented nickel cadmium batteries standard.

[10] 240-62772907, Standard for Stationary Diesel Generator Systems.

[11] SANS 10142-1, The wiring of premises, Part 1: Low voltage installations.

[12] ETDG0446, DC System Design Guide, Rev 2.

[13] IEC 60947-6-1: Low-voltage switchgear and control gear - Multiple function equipment – Transfer switching equipment.

[14] IEC 60947-3: Low-voltage switchgear and control gear – Switches, disconnectors, switch-disconnectors and fuse-combination units.

[15] IEEE 493-2007, IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems.

2.2.2 Informative

[16] FEMA P-1019, Emergency Power Systems for Critical Facilities: A Best Practices Approach to Improving Reliability. September 2014

[17] NFPA 70, National Electrical Code, (NFPA, 2014)

2.3 Definitions

2.3.1 General

Definition	Description
Availability	Availability is the ability of an item under combined aspects of its reliability, maintainability, and maintenance support to perform its required function at a stated instant of time or over a stated period of time. [13]
Critical Facility	A building that is intended to remain operational in the event of extreme events i.e. environmental loading from flood, wind, snow, earthquakes, or tsunamis, or other types of hazards including terrorist physical attacks, cyber-attacks, accidental man-made hazards and large sunspot events (space weather). This classification may also be expanded to include those sites that contain significant quantities of hazardous materials and those sites that serve functions that are critical to ongoing operations of business or government. In model building codes, they are often referred to as essential buildings.
Critical Operations Power System	Power systems for facilities or parts of facilities that require continuous operation for the reasons of public safety, emergency management, national security, or business continuity. [Source: 702.2 of NFPA 70] Some facilities designated as critical facilities must operate continuously. An example is National Control.
Critical site	A site or specific operations / processes / equipment on the site that is critical to ensure network operation or management from a national perspective. This includes black start sites and other sites that meet this categorisation based on a risk assessment.

Definition	Description
Dual corded load	Dual-corded load equipment has two power supplies built into it, with two separate power cords, each capable of powering the equipment. This provides the opportunity to eliminate single points of failure from the power source all the way to the piece of load equipment itself. One cord from each power supply is powered by a separate UPS system, to utilize the redundancy of a 2N standby power system configuration.
Emergency System	Those systems legally required and classed as emergency by municipal, state, federal, or other codes, or by any governmental agency having jurisdiction. These systems are intended to automatically supply illumination, power, or both, to designated areas and equipment in the event of failure of the normal supply or in the event of accident to elements of a system intended to supply, distribute, and control power and illumination essential for safety to human life. [Source: Section 700.2 of NFPA 70] The need for an automatic transfer switch that transfers the load within 10 seconds of loss of normal power and the need for separation from the normal power supply. Emergency systems require permanent power supplies. Emergency systems are typically required in places of assembly and other large buildings that may be occupied by a large number of people.
Legally Required Standby System	Those systems required and so classed as legally required standby by municipal, state, federal, or other codes or by any governmental agency having jurisdiction. These systems are intended to automatically supply power to selected loads (other than those classed as emergency systems) in the event of failure of the normal source. [Source: 701.2 of NFPA 70] Legally required standby systems also require an automatic transfer switch. However, the load must be transferred within 60 seconds of loss of normal power. Legally required standby systems require permanent power supplies. These systems typically serve loads such as heating and air conditioning systems. They may also supply sewage disposal systems, lighting, and some industrial machinery.
Load Profile	A graph of the variation in the electrical load versus time
Optional Standby System	Those systems intended to supply power to public or private facilities or property where life safety does not depend on the performance of the system. These systems are intended to supply on-site generated power to selected loads either automatically or manually. [Source: 702.2 of NFPA 70] There are no requirements for a timed transfer of load for these systems, but a transfer switch is required. Optional systems do not require permanent power supplies; they may be supplied by portable or mobile equipment.
Reliability	Reliability is defined of the ability of a component or system to perform required functions under stated conditions for a stated period of time. [13]
Significant site	A site or specific operations / processes / equipment on the site that are critical to ensure network operation or management from a regional perspective.
Single corded load	Single corded load equipment only has one power supply with one power cord. In order to utilize the redundancy from two independent UPS Systems (2N) an ASTS needs to be used which accepts the independent power supply outputs from the UPS systems and provide a “firm” single output.

2.3.2 Disclosure classification

Controlled disclosure: controlled disclosure to external parties (either enforced by law, or discretionary).

2.4 Abbreviations

Abbreviation	Description
AC	Alternating Current
ASTS	Automatic Static Transfer Switch
ATS	Automatic Transfer Switch
DC	Direct Current
DCC	Diode Combiner Circuit
ESPS	Emergency Standby Power Supply
HVAC	Heating, Ventilation and Air Conditioning
IPS	Interruptible Power Supply
NPS	Normal Power Supply
OU	Operating Unit
PDU	Power Distribution Unit / Distribution Board
SCADA	Supervisory, Control and Data Acquisition
SS	Static Switch
UPS	Uninterruptible Power Supply

2.5 Roles and responsibilities

a) All stakeholders associated with the design, construction, management, operation and maintenance of facilities / sites that require standby power systems shall ensure that the requirements of this document are implemented.

b) The resilience teams in the different OUs shall be responsible to determine how many mobile diesel generators shall be required to adequately meet the autonomy requirements of this document as this decision is influenced by many factors such as distances to sites, accessibility to sites, site drains, available operational resources (staff and vehicles), etc.

Note:
Some equipment are adversely affected (data corruption, etc.) by an interruption of their power supply, therefore it is critical that all operating units ensure that such equipment are identified and mitigating measures implemented to handle these eventualities in the best possible manner.

2.6 Process for monitoring

The DC & Auxiliary Supplies Study Committee shall review this document in line with the standard review cycle or earlier if the need for amendment is deemed critical. Regional and national resilience teams shall ensure that the requirements of this document are adhered to by way of technical audits.

2.7 Related/supporting documents

The following documents are superseded by this document:

a) 240-53114314 (DST_34-1299), Minimum Reliability and Capacity Requirements of Essential DC Power Supplies for various equipment at Distribution Sites.

b) 240-103059202, Capacity of Essential Power Supplies for Telecommunication, Protection and Telecontrol Equipment of the Transmission System.

c) ETDG0446, DC System Design Guide, Rev 2

d) The standby power system requirements of 240-87584120, Emergency Preparedness Standard for PTM&C Equipment, are superseded by this document.

3. Business requirements

3.1 Resilience planning

It is important to consider as part of the planning phase, how the facility / site will function during and after a disaster / incident. This speaks to the systems that need to remain operational for the facility to function effectively. The disaster management plan is a key component in designing the emergency power systems. Once critical functions are identified, the building systems required to support the critical functions can be identified, along with their electrical power requirements; taking cognisance of the changes in normal operational procedures that will be implemented in the event of a disaster, which may serve to reduce the electrical power demands. The potential for outside assistance, in the form of portable emergency generating equipment, for example, should be considered along with any necessary building infrastructure that is needed to accept outside power sources or fuel supplies. The disaster management plan should also consider the length of time before fuel and other supplies, such as lubricating oil and filter stocks, will need to be replenished.

The standby powers systems shall be protected (by way of most suitable placement / location on the site) against natural phenomena such as earthquakes, winds, and flooding, as well as induced phenomena such as fire, explosion, missiles, pipe whips, discharging fluids, CO_2 discharge and other hazards.

3.2 Network configuration and sources of supply

The Power Supply Network can be divided into two sub-networks as indicated in Figure 1:

a) Normal Power Supply (NPS) – supply of all installations and power consumers available in the building / on the site.

b) Emergency Standby Power Supply (ESPS) – supply of all critical installations and power consumers that need to remain operational for some time following an NPS failure. The ESPS can be divided in two types of networks based on the consumer tolerance to supply loss:

   1) Interruptible Power Supply (IPS) – supply of power consumers that can tolerate a break in supply in the event of an NPS failure. Typical loads include air-conditioning loads, etc.

   2) Uninterruptible Power Supply (UPS) – supply of sensitive power consumers (AC and DC loads) that cannot tolerate a break in supply in the event of an NPS failure. Typical loads include emergency lighting, datacentres, communication systems, etc.

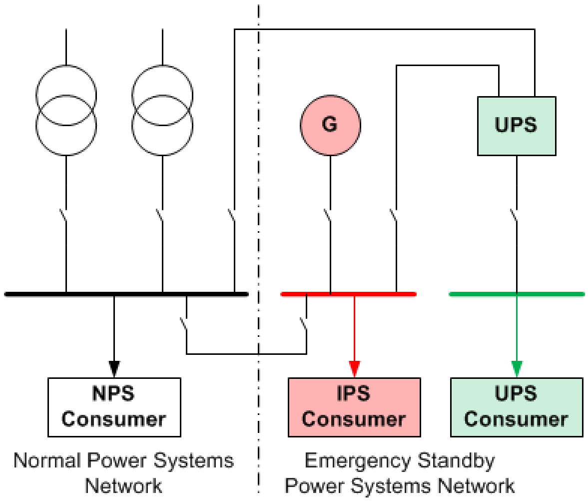


Figure 1: Power Supply Network layout

3.3 Asset Management

Asset management is a critical function to guarantee the availability of standby power systems for any network emergencies.

a) All standby power systems shall be assetised.

b) Maintenance schedules shall be established and implemented.

c) Fuel management shall be implemented to ensure that the fuel quality does not compromise the operation of standby power systems.

3.4 Site Criticality

The criticality of a site relates to the importance of a site / equipment from a network management perspective – how critical that site is in serving a specific purpose. Looking at the structure (hierarchy) of an electricity network, the site importance reduces the further you move away from the power station. However, under a black start scenario, certain sites (regardless of its position in the network) get assigned the same criticality, because they are all equally important to restore the electricity network.

The criticality of a site informs the required standby time as well as the reliability and availability of the equipment at the site to perform their functions effectively.

Table 1 indicates the envisioned standby time requirements (as decided by the National Blackout working group) for the different categories of sites based on their importance to restore the electricity network following a blackout incident. This table is not exhaustive and shall be used as a starting point to identify other facilities which may have been omitted. It is critical to note that if an intermediate site provides a telecommunications link between higher priority sites, then the priority of telecommunications standby power system for the intermediate site shall default to the higher priority, else it becomes the weakest link in the chain.

Priority 1 sites are all sites where Operation and Information systems are located that are necessary for support response and recovery activities in the extended interruption of supply. These sites would normally also be the sites where services like the SCADA support, Resource Management Centres and Contact Centres are located. To optimise the use of available standby power systems infrastructure the various critical service areas shall as far as practically possible, be co-located. In these instances, all critical service areas within the same building, complex or campus shall be connected to the standby power systems reticulation network.

At some priority 1 sites, only certain equipment might be required to be operational during the network restoration period e.g. at a Transmission substation, the telecommunications equipment (fibre network equipment) and SCADA equipment needs to be operational to ensure telecommunications availability and remote operability of network equipment. Therefore, only that equipment would need to comply with the increased reliability, availability and standby time requirements.

The preservation of standby power at site to enable efficient network restoration is discussed later in this document.

Priority 2 sites are all sites where support services / functions are located to enable and facilitate the response and recovery effort. This includes engagement with internal and external role players. These sites have a lower priority, but are usually located at priority 1 sites.

Priority 3 sites are all sites that are not required to be operational during the network restoration period.

Table 1: Envisioned standby times for Eskom sites for a blackout scenario

Standby	**7 Days**	**3 Days**	**Several hours - 1 Day**
	Priority 1	**Priority 2**	**Priority 3**
Site Criteria	Operation and Information systems that support response and recovery activities in the extended interruption of supply.	Enabling support service to enable and facilitate the response and recovery effort. This includes engagement with internal and external role players.	Operational and normal business operations.
1	National Control Centre	Customer Contact Centre	Walk - In Centre
2	Regional Control Centre	Work / Resource Management Centre	Transmission Customer Load Centre
3	Backup Control Centre	Regional Offices (Service Room)	Distribution Customer Network Centres
4	Data Centre (IT)	Power Station Office Block	Local Offices
5	Emergency Response Command and Control (ERCC) / Provincial Joint Command and Control (PJCC)	Rotek	Training Centres
6	Divisional Tactical Command Centre (DTCC) / Provincial Emergency Operating Centre (PEoC)	District Emergency Operating Centre (EoC)	Eskom Conference Centre
7	Generation Engineering Desk Centre (EDC)		Stores
8	Integrated Generation Command Centre (IGCC)		Substations
9	Nerve Centre		Telecommunication sites
10	Generation Emergency Preparedness (EP) Centre		Power stations
11	Rotek "Monitoring Centre"		
Note: The standby times in the table are only applicable to critical facilities within the mentioned buildings/sites.			

3.5 System autonomy

Standby time or system autonomy is the time period for which critical processes or activities are kept operational when the NPS fails. It is important to note that NPS does not only refer to the utility supply, but also includes the energy storage charging equipment. The standby time is necessary to allow critical equipment to safely shutdown or continue operating or provide power to equipment that supports essential activities. The standby time of each site is determined by the period that it would take to restore the NPS to the site or to put alternative measures in place.

Priority 1 and priority 2 sites either form part of the critical path for network restoration or supports the restoration process and due to the complex nature of the network restoration following a black-out incident which involves the co-ordination of many different resources and stakeholders, the standby times at these sites are significantly longer than that of the priority 3 sites which allows for normal localised network incidents.

3.5.1 Influencing factors

In cases where the standby time is only needed to safely shutdown a process / activity, the main influencing factor is the load profile.

In other cases (majority of instances) where the processes or activities need to remain operational until such time that the NPS is restored, the following factors become important:

a) The importance of the site / equipment from a network management perspective.

b) The position of the site on the network re-energisation time schedule. Sites that are closer to the black start origin will be re-energised earlier than sites that are located further away.

c) The distance of the site from the nearest technical service centre.

d) The accessibility of the site. Sites that are close to national highways and have normal road access are easier / faster to reach compared to sites that are in rural areas where an off-road vehicle is required or access needs to be arranged.

e) The availability of spares – is it readily available or has to be sourced from a central location that could take several hours.

f) The accessibility of the site to the electricity network (grid-connected). Sites that are not connected to the grid and rely on renewable energy sources (wind or solar) require much longer standby times due to the variability of the energy source.

g) The expected length of time needed to replenish generator fuel stocks and to perform preventative or breakdown repairs. A risk assessment study shall be conducted that address the following aspects:

   1) Contracts with fuel suppliers, including delivery,

   2) Need for alternative fuel sources,

   3) Capabilities and authorization to deliver fuel and critical maintenance supplies (e.g. filters) within restricted disaster zones,

   4) Generator maintenance, testing, repair, and

   5) Legislative requirements (National codes and standards or municipal bylaws) that dictate the maximum allowed fuel storage at site.

h) Implementation timing – some equipment or personnel may not be immediately in place for an emergency. Plans must consider the timing necessary to place important elements into operation.

3.5.2 Standby time enhancement measures

3.5.2.1 A load shedding schedule shall be compiled for all priority 1 – and priority 2 sites in consultation with all stakeholders. This is necessary, as a last resort, to identify lower priority essential loads that may be disconnected in an effort to keep essential equipment operational for as long as possible, in cases where access to fuel for extended back up power supply becomes impossible or where standby power availability cannot be sustained for as long as required with all essential loads connected.

3.5.2.2 The implementation of renewable energy supplies to augment the NPS could assist in increasing the standby time and reduce the need to refuel. If designed correctly, the renewable system could ensure that batteries are recharged during the sunlight hours or when wind power is available.

3.5.2.3 Upon been informed of extended network interruptions that exceed the normal standby times for priority 3 sites, it is incumbent of Operating Units to review the need to disconnect load equipment that are not required during the restoration period as batteries that remain discharged for prolonged periods could suffer irreparable damage.

3.5.3 Situational awareness

National Control shall have a national overview of standby power systems' state-of-charge and state-of-health at all priority 1 and priority 2 sites.

3.6 Standby power system topologies

In this section the different standby power system topologies that are typically used in Eskom are reviewed.

3.6.1 System redundancy

When discussing redundancy of a system, it is common to refer to "what is required" as "N" (for number). If a facility has two standby generators, and both are required to carry the building load during a power outage, N is equal to two. If a third generator was added, the redundancy of the power generating system would become "N + 1". There would also be 50% redundancy in standby generator power. If the facility has two standby generators, and only one is required, the redundancy would also be called "N + 1". This could also be called "2N", to show there is 100% redundancy in standby generator power. However, it depends on how the generators are interconnected to determine which term is preferred. If the generators are in parallel (connected to a common output bus or sharing a common power path to the load equipment) it would be "N + 1". If they are totally independent of one another (connected to separate bus bars), the redundancy is "2N".

3.6.2 DC Systems

The simplest application of a DC standby power system is indicated in Figure 2 consisting of a single battery charger (N), a single parallel connected battery bank (N) and a single Distribution Board (DB) / Power Distribution Unit (PDU). Under normal conditions the battery charger keeps the battery charged and also supplies the connected load equipment. During an AC supply and / or rectifier failure, the load will continue to be powered without a break from the battery for the designed standby time. This system topology has the lowest availability and reliability figures.

It is typically deployed at sites with load equipment requiring a specific DC voltage e.g. 110V for protection equipment at Distribution Substations. If another voltage level is required for other equipment at the site, a DC-DC Converter is used e.g. 110V/48V converter to supply supervisory and telecommunications equipment. This obviates the need to install an additional DC system only for the supply of 48V to the other equipment. The design engineer shall perform a lifecycle cost analysis to determine the least cost solution that meets the technical requirements.

The reliability and availability of this system may be improved with the addition of redundant components (e.g. additional battery charger module) which would result in an N+1 system topology – see Annex A.

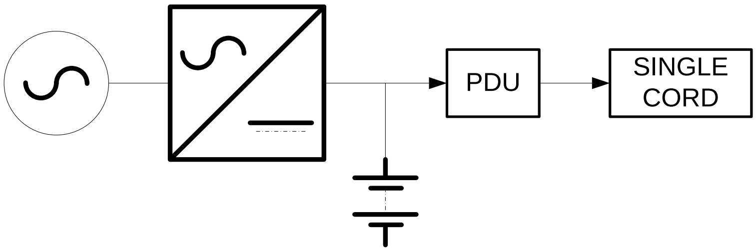


Figure 2: Single DC System

To further improve the reliability and availability of the Single DC System, an alternate power supply (normally a diesel generator) which acts as a backup to the utility supply is installed as indicated in Figure 3.

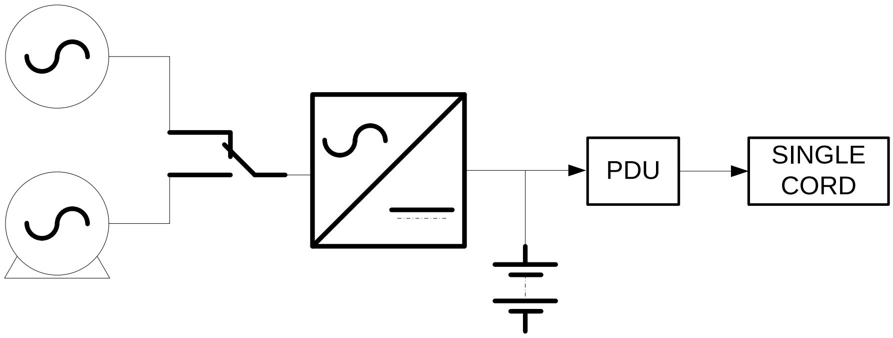


Figure 3: Single DC System with standby generator

The highest reliability and availability figures are obtained with the 2N topology indicated in Figure 4. The availability of the dual redundant power supply paths are optimised with the use of a diode combiner circuit (DCC) supplying single-corded loads and dual-corded load equipment fed from both power supply paths.

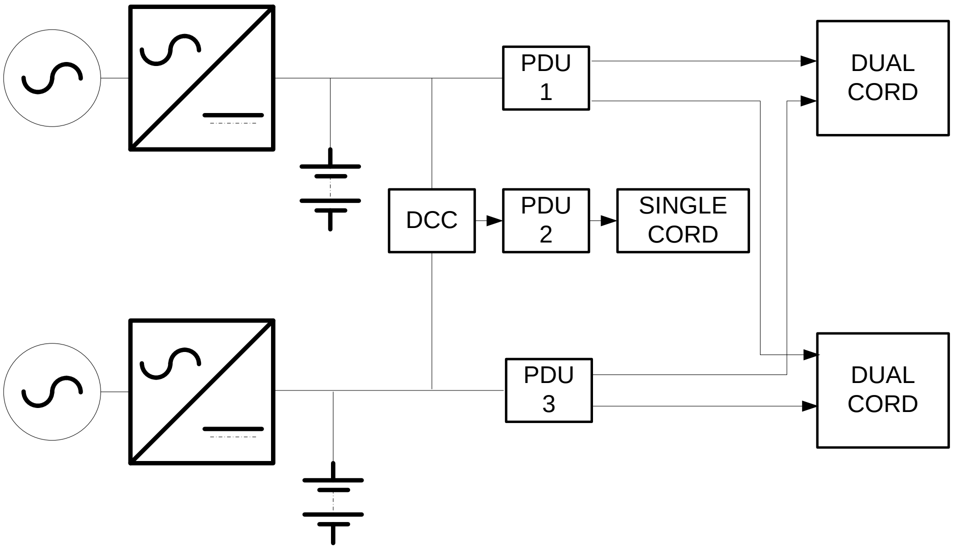


Figure 4: Dual redundant DC System

3.6.3 UPS Systems

The simplest application of an UPS system is indicated in Figure 5 and consists of a single UPS (N), a single parallel connected battery bank (N) and a single Distribution Board (DB) / Power Distribution Unit (PDU). Under normal conditions the UPS keeps the battery charged and also supplies the connected load equipment. This system topology has the lowest availability and reliability figures.

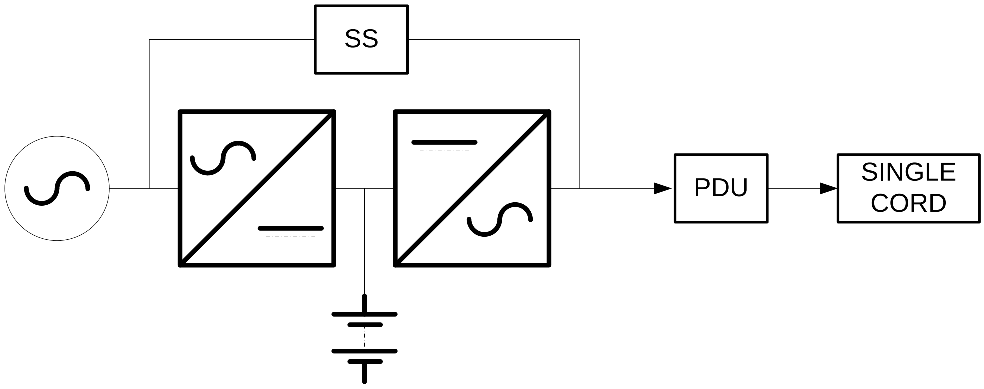


Figure 5: Single UPS System

The highest reliability and availability figures are obtained with the 2N topology indicated in Figure 6. The availability of the dual redundant power supply paths are optimised with the use of an ASTS supplying single-corded loads and dual-corded load equipment fed from separate power supply paths.

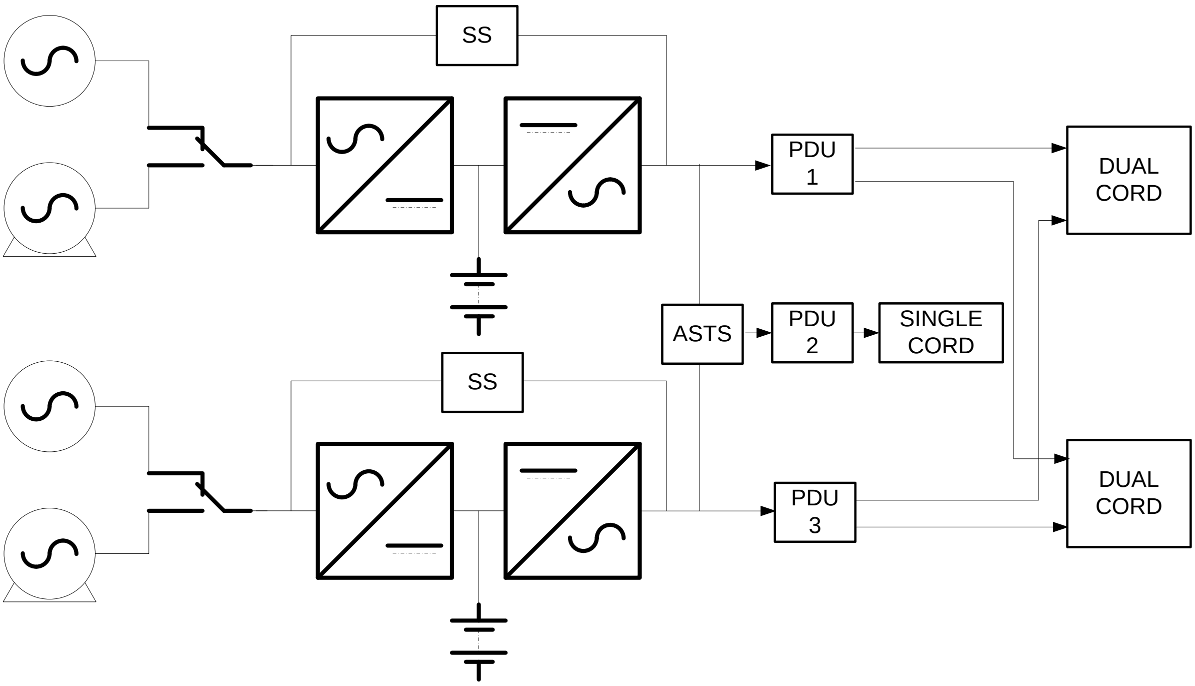


Figure 6: Dual redundant UPS System

3.7 Reliability and availability

This section is intended to explore the different standby power system configurations (DC and AC) that are used in Eskom and evaluate their availability and reliability by using the MTBF figures as quoted in IEEE 493-2007, IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems.

This will not give the actual reliability and availability figures for the equipment used in Eskom, but it will provide a means of comparing different standby power system configurations with each other.

Simply put availability is a measure of the % of time the equipment is in an operable state while reliability is a measure of how long the item performs its intended function.

Reliability is time dependent which means that the longer the time period the lower the system reliability will be, whereas availability is more or less independent of time and lends itself to be a better metric to compare different system configurations. However, availability does not tell the full story, because it is just a combination of how often a system fails and how quickly it is repaired and does not tell us how often a failure occurs. Critical facilities require both high availability and high reliability.

There are two general rules to improve the reliability of a system:

a) the fewer components there are that are required to operate the system, the more reliable it will be (each component can be considered as a “link” in the overall reliability “chain” and a chain is only as strong as the weakest link);

b) the reliability is improved by the elimination of “single points of failure” (SPOF) by the introduction of redundant components (*Each “link” in the reliability “chain” is an SPOF and the failure of any “link” can cause the “chain” to fail. If a second “chain” is introduced which on its own can also carry the full system load, then the SPOF is eliminated and the system reliability drastically improved*).

Table 2 shows the different availability and reliability figures for different UPS system topologies. It is evident that the reliability and availability figures improves from a single system (N) to a dual redundant system (2(N+1)), due to the fact the SPOFs are removed. In the case of a 2N system, an entirely separate fully rated system is installed for this purpose. Each power supply path can carry the entire load, which means that the maximum loading per power supply path is 50% of the system rating. Optimal use of the redundant supply path is accomplished with the introduction of an ASTS for single-corded loads or use of dual corded loads. The same topologies can be used in DC systems with similar improvements.

Table 2: Reliability and availability of different system topologies [15]

Topology (Figure #)	Description	Loads	Availability (A_i)	Probability of failure [1] (5 years) [%]
N+1 (Figure 7)	Generators: • 2 x Generators connected to a common output bus (generator-paralleling switchboard) • 1 of 2 generators are required • Common bus ⇒ N+1 UPS system: • 3 x UPS modules connected to a common output bus • 2 of 3 UPS modules are required • Common bus ⇒ N+1	Single corded	0.9999340	39.95
2N (Figure 8)	Generators: • 2 x Generators sets connected to separate output busses • 2 of 2 generators are required / set • Separate busses ⇒ 2N UPS system: • 2 x UPSs connected to separate output busses / Distribution Boards • 4 of 4 UPS modules / UPS are required • Separate busses / DBs ⇒ 2N	Single corded supplied via ASTS	0.9999490	29.80
		Dual corded	0.9999913	16.61
2(N+1) [2] (Figure 9)	Generators: • 3 x Generators connected to a common output bus (generator-paralleling switchboard) • 2 of 3 generators are required • Common bus ⇒ N+1	Single corded supplied via ASTS	0.9999494	28.07
		Dual corded	0.9999914	16.49

Topology (Figure #)	Description	Loads	Availability (A_i)	Probability of failure [1] (5 years) [%]
	UPS system: • 2 x UPSs connected to separate output busses / Distribution Boards • 4 of 5 UPS modules / UPS are required • Separate busses / DBs ⇒ 2(N+1)			
Notes: 1) Probability of failure = (1 – reliability). 2) This topology is not a true 2(N+1) topology. It is actually a hybrid between N+1 and 2(N+1).				

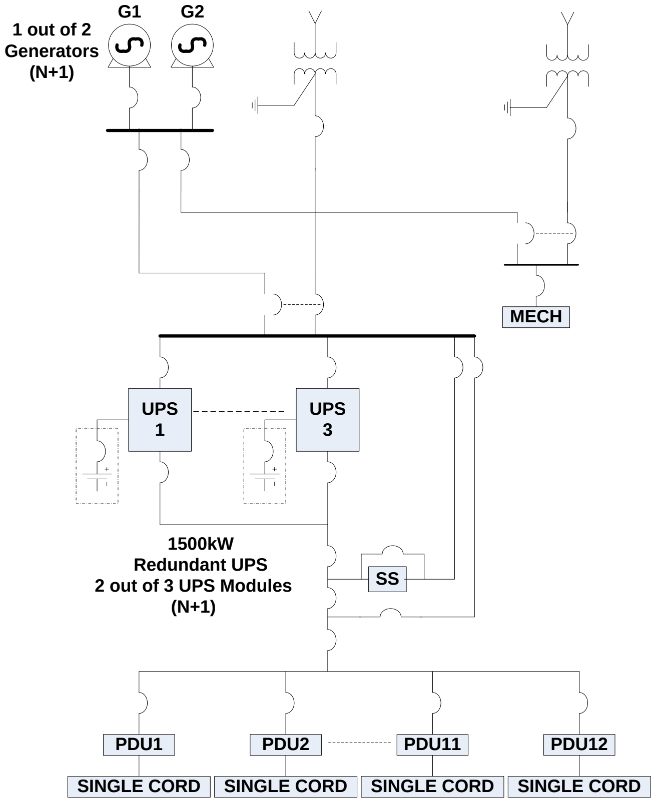


Figure 7: N+1 Standby Power System single line diagram [15]

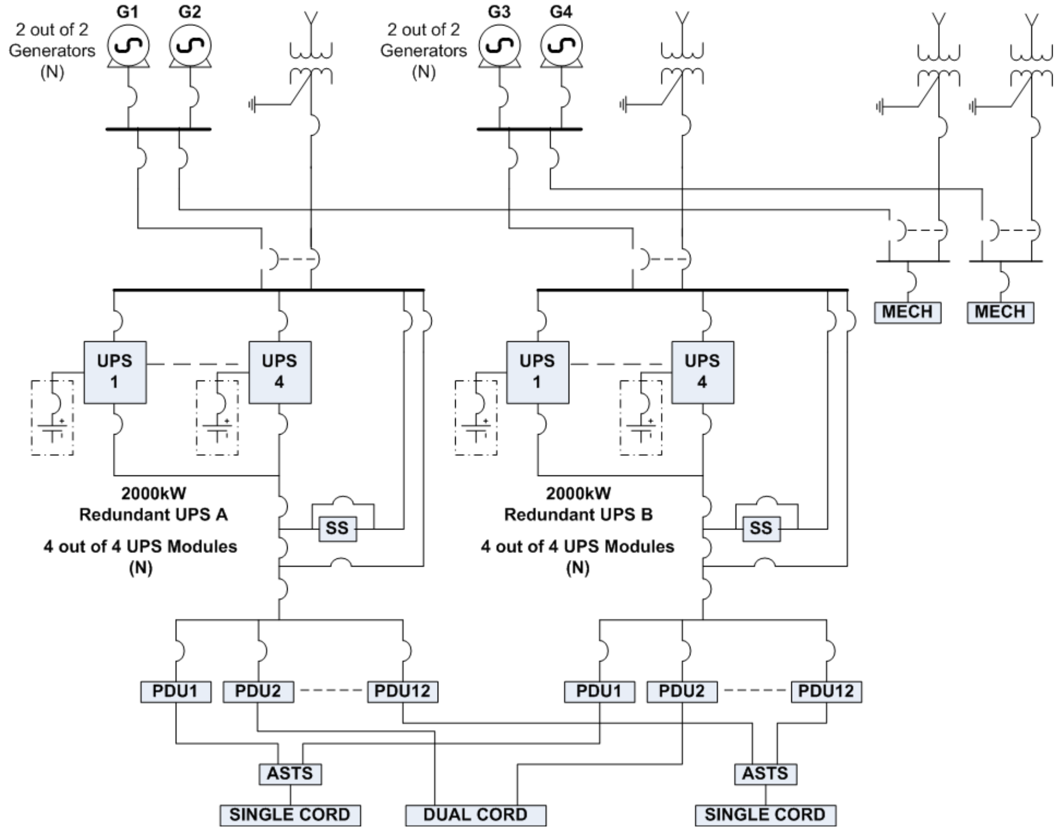


Figure 8: 2N Standby Power System single line diagram [15]

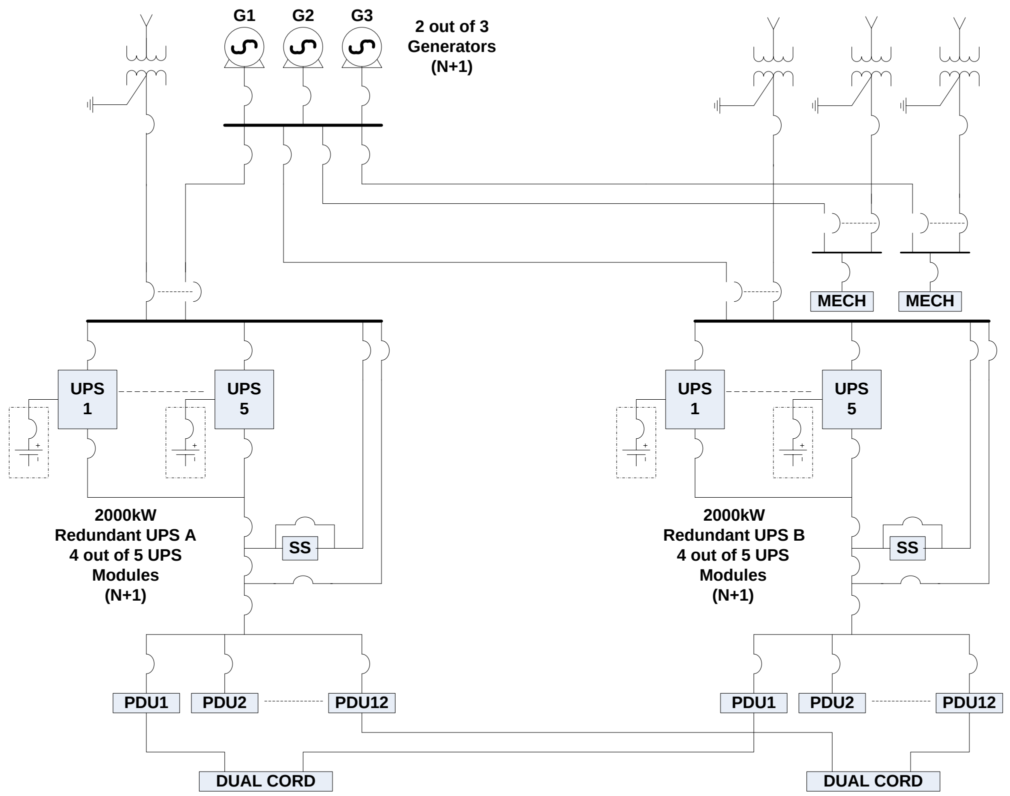


Figure 9: N+1 Generator and 2(N+1) UPS Standby Power System single line diagram [15]

3.8 System topologies and standby times for different priority sites

In this section the different system topologies and standby time requirements commensurate with the different site / system priorities are discussed. It should be noted that there may be cases where certain equipment / systems / areas within a specific site are regarded as priority 1 due to their importance to the network restoration process.

The requirements of this section apply to the majority of sites in Eskom. However, special cases shall be reviewed and assessed on a case by case basis.

a) Essential loads at substations include the protection schemes, telecommunications equipment, SCADA equipment, emergency lights and security systems.

b) Essential loads in Office buildings include HVAC, lighting, server rooms / data centres, security systems, fire detection systems, emergency preparedness systems, teleconference facilities, telecommunications systems and SCADA systems located in essential areas.

c) Essential areas in office buildings include inter alia Network Management Centres, Contact Centres, Resource Management Centres, Command Centres, etc.

d) All these essential loads / areas shall be powered from standby power systems.

e) The design engineer, in consultation with the customers / site stakeholders shall identify which of the essential loads are interruptible and which are not.

f) Interruptible – and uninterruptible essential loads shall be powered from the generator DB and UPS system (AC loads) or DC system (DC loads) DB, respectively.

g) Priority 1 and priority 2 sites are normally easily accessible due to the fact that they are either located within municipal areas or have decent road infrastructure available.

h) Table 3 and Table 4 indicate the required standby times for priority 1 sites and priority 2 sites, respectively.

i) It is important to note that in order to maintain the required system reliability and availability (discussed in section 3.7), the stated standby times apply per system e.g. in the case of a dual redundant system with a battery bank per system; each battery bank needs to provide the stated standby time.

j) The total required standby time (T_{total}) is a combination of the energy storage standby time (T_{ES}) normally provided by battery banks and the extended backup standby time (T_{EB}) normally provided by a diesel generator, as indicated in Equation 1.

$$T_{total} = T_{ES} + T_{EB} \qquad \text{Equation 1}$$

k) The balance of the standby time not covered by the battery banks shall be catered for by having sufficient fuel supplies available on site up to the maximum legally allowed volume for the site.

l) The site loading and efficiency of the diesel generator (load factor) will determine the maximum time period that the load can be supplied from the on-site fuel supply.

m) In cases where a shortfall exists, this shall be covered by ensuring that reliable and effective fuel replenishment processes are in place.

n) Some operating units may opt for the use of roving mobile diesel generators that are deployed to various sites based on the operational need. However, the battery recharge times and distances between sites need to be carefully considered when this option is chosen.

o) Table 3 shows the required system topologies for priority 1 sites and the different system voltages needed to power the different critical load equipment. Telecommunications – and SCADA equipment uses 48Vdc and the protection equipment (schemes) use either 220Vdc or 110Vdc depending on the physical size of the site. UPS Systems are required where equipment that operate from AC power, usually information technology equipment, are used e.g. workstations or datacenters.

p) Single (N) stationary diesel generators are recommended for priority 1 substations and telecommunications sites to increase their standby times.

q) Roving mobile diesel generators may be deployed to these sites in case of breakdowns.

Table 3: Required topologies and standby times for Priority 1 sites / facilities

Site / Area	System	Topology	Standby Time [h]	
			System [1)]	Total
National Control Centre Backup National Control Centre Regional Network Management Centres Tactical Command Centres	48V DC	2N / 2(N+1)	4	168
	UPS	2N / 2(N+1)	4	
	Generators	2N / 2(N+1)	T_{EB}	
Transmission Substation	48V DC	2N / 2(N+1)	12	168 [2)]
	110V/220V DC	2N / 2(N+1)	12	
	Generators	N	T_{EB}	
Distribution Substation (≤ 200km)	48V DC	2N / 2(N+1)	12	168 [2)]
	110V DC	N / 2N / 2(N+1) [4)]	12	
	Generators	N	T_{EB}	
Distribution Substation (> 200km)	48V DC	2N / 2(N+1)	18	168 [2)]
	110V DC	N / 2N / 2(N+1) [4)]	18	
	Generators	N	T_{EB}	
Telecommunications Site (µWave / Fibre) [3)]	48V DC	2N / 2(N+1)	48	168 [2)]
	Generators	N	T_{EB}	

Notes:

1) T_{EB} indicates the standby time covered by the generator fuel capacity as discussed in 3.8 j). The other figures indicated refers to the standby time covered by the battery banks (T_{ES}) as discussed in 3.8 j).

2) This requirement only applies to the SCADA equipment and Telecommunications backbone equipment at these sites. Each site shall also be equipped with connection point for a mobile diesel generator.

3) This shall include Telecommunications regeneration sites.

4) The 110V DC system topology shall be determined by the design engineer based on the network importance of the site.

r) Table 4 shows the required system topologies for priority 2 sites and the different system voltages needed to power the different critical load equipment.

Table 4: Required topologies and standby times for Priority 2 sites

Site / Area	System	Topology	Standby Time [h]	
			System [1)]	Total
Customer Contact Centre Resource Management Centre Customer Service Centre (Walk-in Centre) Local Offices Stores Training Centres / Conference Centres Transmission Customer Load Centre Distribution Customer Network Centre	48V DC	2N / 2(N+1)	4	72
	UPS	2N / 2(N+1)	4	
	Generators	N	T_{EB}	

s) Priority 3 sites are all sites that are not required to be operational during the network restoration period. These sites will be energised as the network is progressively re-energised. These system requirements are based on the importance of the site from a network impact (hierarchy) perspective e.g. what downstream networks are affected by this site failing.

t) The standby times (indicated in Table 5) are suited to cater for normal regional (localised) network incidents.

u) Extended backup power systems are not required at most of these sites, but suitably rated connection points shall be made available for the safe connection of mobile diesel generators.

v) It is the responsibility of the OU resilience team to determine and motivate the need for stationary diesel generators at priority 3 sites as some services may exist that need this.

w) Table 5 shows the required system topologies for priority 3 sites and the different system voltages needed to power the different critical load equipment.

x) Telecommunications systems used in areas where UPS systems are deployed (usually office buildings) shall where possible be powered from the UPS systems (AC supply) to optimise the use of available standby power systems. This arrangement does not only reduce the capital cost, but also the associated maintenance costs.

y) Standby times for emergency lights shall be a minimum of 4 hours at sites (e.g. control / equipment rooms at substations and telecommunications sites) which are not manned.

z) Emergency lights in office buildings shall have a minimum standby time of 4 hours and shall also be connected to the standby generator reticulation system for extended backup – this is especially required in essential areas.

aa) Security systems are required to ensure that the site is protected at all times, hence the standby time of these systems shall be in line with the overall required standby time for the site as indicated.

Table 5: Required topologies and standby times for Priority 3 sites

Site / Area	System	Topology	Standby Time 1) [h]
Transmission Substation 2) 3) [3] Power Station HV Yards 2) 3) [3]	48V DC	2N / 2(N+1)	12
	110V/220V DC	2N / 2(N+1)	12
Radio Stations at Power Stations 2) [3]	48V DC 4)	2N / 2(N+1)	12
ETN Equipment Rooms within Power Stations 5) [3]	48V DC 4)	2N / 2(N+1)	8
Distribution Substation (≤ 200km) 6) [7]	48V DC	N	12
	110V DC	N	12
Distribution Substation (> 200km) 6) [7]	48V DC	N	18
	110V DC	N	18
Distribution Substation (Brickbuild substation) [7]	24V/32V/36V/110V DC	N	12/18
Distribution Substation without supervisory 7) [7]	110V DC	N	240
Grid tied Telecommunications Backbone site	48V DC	2N	48
Grid tied Telecommunications Access or Area Radio site 2)	48V DC	N	72
Off-grid Telecommunications Access or Area Radio site 2)	48V DC	N	120
Off-grid Telecommunications Backbone site	48V DC	2N	120

Site / Area	System	Topology	Standby Time [1] [h]

Notes:

1) In the case of dual systems, it refers to the standby time per battery bank.
2) Secondary backup power to be provided by Mobile Diesel Generators or Remote Start stationary (permanently installed) generators. A suitably rated connection facility shall be made available at site for mobile diesel generator connection.
3) Each DC maintenance section shall have access to at least one suitably rated mobile diesel generator set.
4) DC Systems coupled to a common DC busbar ⇒ use of a Diode Combiner Circuit.
5) Power Stations diesel generators to provide secondary backup power.
6) The distance of the site to the nearest DC Control Plant Maintenance Section.
7) Although there is a drive to ensure visibility of all sites, there are some Distribution Substations that do not have SCADA connectivity. The 10 days allowed for is to ensure that the Customer Network Centre (CNC) staff can detect NPS failure during their weekly site inspections.
8) If a Telecoms Backbone site is Off-grid, then the design would need to be approved as non-standard through the relevant technical governance committees.
9) Where the AC supply to sites (backbone sites only) can regularly be disrupted for long periods due to weather or poor local AC supply, the standby time can be increased to cater for such disruptions.

3.9 Equipment requirements

a) Stationary diesel generators shall comply with the requirements of 240-62772907, Standard for Stationary Diesel Generator Systems [10].

b) Mobile diesel generators shall comply with the requirements of 240-112691204, Specification for Mobile Diesel Generator Systems [4].

c) Battery chargers, Uninterruptible power supplies, DC-DC converters and inverters (DC-AC) shall comply with the requirements of 240-53114248, Specification for Thyristor and switch mode chargers, AC/DC to DC/AC converters and inverter/uninterruptible power supplies [6].

d) The Automatic Transfer Switches (ATS) shall comply with the following:

   1) The ATS shall comply with the requirements of IEC 60947-6-1, Low-voltage switchgear and control gear – Multiple function equipment – Transfer switching equipment [13] and IEC 60947-3, Low-voltage switchgear and control gear – Switches, disconnectors, switch-disconnectors and fuse-combination units [14].

   2) Rated operational voltage and current capacity, number of poles (fully rated) and characteristics shall comply with IEC 60947-6-1 [13] and IEC 60947-3 [14].

   3) The ATS supplied shall be designed and built as a fully integrated, maintenance free product (power switching, motorisation and ATS Control), shall be of the same recognized manufacturer and shall be tested to IEC 60947-6-1 [13] as one complete unit.

   4) The ATS installation and operation shall comply with the SANS 10142-1, The wiring of premises, Part 1: Low voltage installations [11], which requires that where an alternative supply is provided to an installation or part of an installation as a switched alternative to the main supply, the change-over switching device shall disconnect the main supply before the alternative supply is switched in.

   5) The change-over switching device shall be both electrically and mechanically interlocked in such a way that the main supply and the alternative supply cannot be connected to the installation or part of the installation at the same time.

3.10 Priority 1 site requirements

Priority 1 sites are critical for the effective management of the utility network and in ensuring an efficient and speedy restoration of the grid following a black-out incident.

3.10.1 General

From an operational perspective the following functional requirements need to be fulfilled:

a) The site needs to be operational 24/7/365.

b) Complete redundancy from the utility service entrance all the way to the critical loads.

c) The elimination of all single points of failure as far as possible.

d) The configuration shall be fault tolerant.

e) Planned maintenance shall be possible on system components / sub-systems without affecting the connected load or without transferring the load to bypass mode, which would expose the load to unconditioned power.

f) The HVAC systems shall also be dual redundant to ensure that the critical load equipment operates within their designed temperature range and also to ensure that the environment in essential service areas remains comfortable for staff to continue.

g) A mimic display shall be available at the system controller to show the status of all supplies (utility, generator, UPS systems and DC systems) and the positions of all applicable switches.

3.10.2 System topology

The standby power systems at these sites shall comply with the following requirements (see Figure 10):

a) All critical services shall be identified and connected to the standby power systems reticulation network.

b) The standby power systems topology shall be as a minimum dual redundant (2N or 2(N+1) topology) with two independent power supply paths feeding all critical loads. Each path shall be rated to carry the full critical load of the facility.

c) The two independent power supply paths shall be physically separated to prevent a common physical incident from affecting both paths.

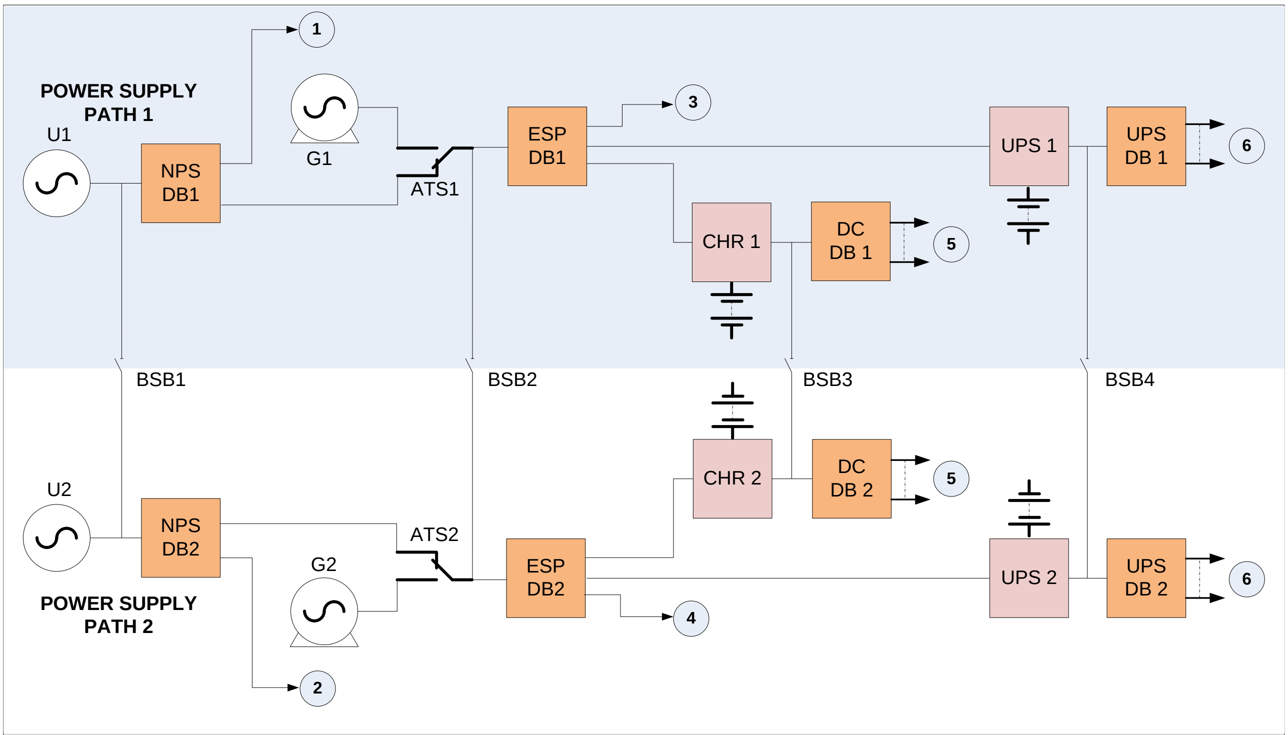
d) The utility supplies shall be from two independent network locations e.g. it shall if practically possible and if the budget allows not be two feeders from the same substation.

e) The utility supplies shall terminate on normal power supply DBs (NPS DB) from where the power shall be reticulated to the normal power supply loads and critical loads.

f) Automatic transfer switches (ATS) shall be used to switch between normal utility supply and the alternate diesel generator supply. The ATS switch shall employ a break-before-make operation and prevent paralleling of supply sources.

g) Each diesel generator shall be rated to carry the critical loads fully. It shall be rated as mission critical / prime diesel generators required to run for extended periods of time at full load.

h) The output of the ATS shall be connected to the Emergency Power Supplies DB (EPS DB) from where power shall be reticulated to all critical loads that may be interrupted for the period needed for the diesel generator to start-up and be ready to accept load (<30 seconds).



1 – Other NPS DB1 Loads
2 – Other NPS DB2 Loads
3 – Other Interruptible ESP DB1 Loads
4 – Other Interruptible ESP DB2 Loads
5 – UPS DC Circuits to sub-DBs or Loads
6 – UPS AC Circuits to sub-DBs or Loads

ATS : Automatic Transfer Switch
BSB : Bus Section Breaker
CHR : Charger
DB : Distribution Board
DC : Direct Current

ESP : Emergency Standby Power
G : Generator
NPS : Normal Power Supply
U : Utility Supply
UPS : Uninterruptable Power Supply

Figure 10: Emergency Standby Power Systems single line block diagram for a Priority 1 site

i) Each UPS System shall have wrap-around circuits to enable easy replacement when necessary without affecting the load equipment.

j) The UPS Systems and DC Systems shall be connected to the EPS DB.

k) The UPS Systems and battery chargers shall be either standalone or modular systems.

l) The UPS Systems and battery chargers in each power supply path shall be rated to carry the critical loads fully.

m) Each UPS DB shall supply the various DBs in the critical service areas. Each critical area shall have a UPS 1 DB and UPS 2 DB from where the critical loads shall be supplied.

n) Dual-corded load equipment (e.g. load equipment with dual power supplies) shall as far as possible be used in priority 1 sites to make optimal use of the dual redundant power supply paths available. See Figure 11.

o) Single-corded AC load equipment (e.g. workstations) shall be powered from automatic static transfer switches (ASTS) which accepts two independent inputs from the two UPS DBs and provides a secure (firm) output to the load equipment. See Figure 11.

p) In the case of DC circuits, a diode combiner DB shall be installed to provide firm supply to single-corded DC load equipment.

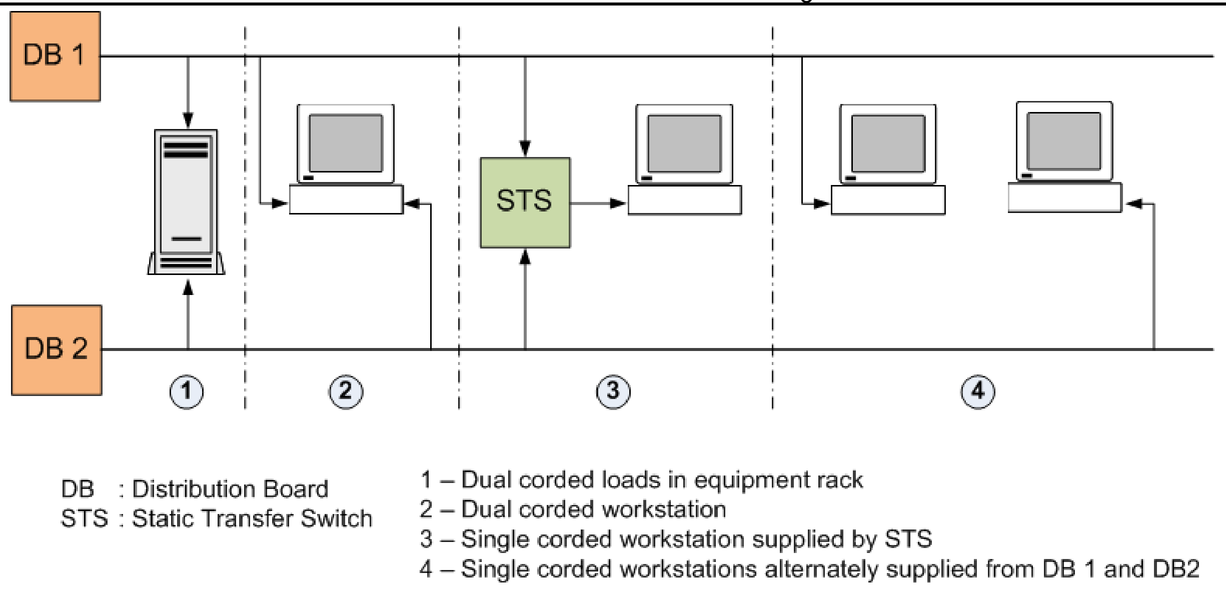


Figure 11: Arrangement of Dual redundant supplies to load equipment

q) Each UPS DB shall supply the various DBs in the critical service areas. Each critical area shall have a UPS 1 DB and UPS 2 DB from where the critical loads shall be supplied.

r) The requirement for continuous lighting in critical areas shall be met by supplying every alternate light fitting from an independent UPS power supply path.

3.10.3 Power Management System

a) A Power Management System (PMS) shall be employed at all the priority 1 sites related to management and operation of the electricity network. The purpose of the PMS is to ensure the optimal utilisation and safe operation of all power sources at the site. This may be implemented as part of the Building Management System (BMS) of the site.

b) The PMS shall have the following features:

c) Provides a holistic overview (single line diagram) of the electrical reticulation network of the site at the control centre.

d) The diagram shall include all power sources, power conditioning equipment (utility supplies, diesel generators, UPS systems, DC systems) and the emergency standby power systems network.

e) Display the real-time states of all switching equipment.

f) Display the real-time state-of-health of all standby power systems equipment (Ready, Warning, Alarm).

g) Display the real-time fuel of all diesel generator tanks.

h) Display the real-time state-of-charge of all energy storage equipment.

i) Date-time-stamped log all system events, alarms and operations.

j) Display and record real power, reactive power, apparent power, power quality parameters, voltages and currents at critical distribution boards. This data shall be used to monitor and manage the power usage on the site.

k) Implement a load shedding schedule to shed less critical loads when required.

l) Implement automated system switching schemes under different power supply conditions to ensure continuous operation of critical loads as detailed in 3.10.4.

3.10.4 System operation

A system controller shall be employed to implement the functionality as discussed in the next sections.

3.10.4.1 System Operation due to utility supply failure

a) Under normal conditions, the two supply paths shall be independent and operated as such.

b) If one of the utility supplies fails:

1) The generator shall not be started.

2) Isolate the faulty utility supply at the input circuit breaker to the facility.

3) Close utilities bus-section breaker to ensure that both supply paths are powered by the healthy utility supply.

c) If both utility supplies fail:

1) The system controller shall switch both ATSs to the OFF position.

2) Both backup generators will start upon loss of utility supply. This proves that both generators are available and ready to accept load.

3) However, in order to ensure that the generators run as efficiently as possible, the system controller shall only allow one generator to run at a time. This will also ensure optimised fuel usage.

4) The system controller shall further ensure that the runtime of the individual generators are balanced as far as possible, by alternating the running of the generators. This transition shall happen when the running / active generator has reached a low fuel level (20%) and needs to be refuelled.

5) The system controller shall switch the ATS of the generator with the least runtime to the generator supply position.

6) The system controller shall close the bus-section breaker of the ESP DBs. This sequence will ensure that 50% step loads are picked up at a time.

7) Upon return of utility supplies, the system controller shall first open the bus-section breaker of the ESP DBs.

8) The system controller shall switch the ATS of the active generator to the OFF position. The generator will be allowed to cool down and switch off.

9) If both utility supplies return, then the system controller shall switch both ATSs to the normal supply positions.

10) If only one utility supply returns, then the system controller shall follow the switching procedure as described in 3.10.4.1 b).

3.10.4.2 System Operation due to UPS failure

a) Under normal conditions, the two supply paths shall be independent and operated as such.

b) If one of the UPS fails and transfers to bypass:

1) The loads will be supplied by utility supply via the one supply path and by the healthy UPS via the other supply path.

2) In this case the closing of the bus-section breaker between the UPS DBs is not required.

c) If one of the UPS fails to the extent no output power is available (it does not transfer to bypass):

1) The output of the failed UPS, any bypass circuits and wrap-around circuits shall be completely isolated.

2) It is now safe to close the bus-section breaker between the UPS DBs to supply the load equipment via both supply paths.

d) Apply the reverse switching procedure when the repaired UPS becomes available again.

4. Authorization

This document has been seen and accepted by:

Name and surname	Designation
Prince Moyo	Power Delivery Engineering GM
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Richard McCurrach	Senior Manager – PTM&C CoE
Prudence Madiba	Senior Manager – Electrical and C&I Engineering
Kashveer Jagdaw	DC & Auxiliary Supplies SC Chairperson

5. Revisions

Date	Rev	Compiler	Remarks
March 2020	2	T Jacobs	Section 3.4: Added "It is critical to note that if an intermediate site provides a telecommunications link between higher priority sites, then the priority of telecommunications standby power system for the intermediate site shall default to the higher priority, else it becomes the weakest link in the chain." Table 3: Updated Notes 2) and 3): Note 2) This requirement only applies to the SCADA equipment and Telecommunications backbone equipment at these sites. Each site shall also be equipped with connection point for a mobile diesel generator. Note 3) This shall include Telecommunications regeneration sites. Updated Table 5: Removed Radio Repeater stations, Renewable Radio sites, Grid tied Radio sites, Grid ties PDH sites, Grid tied SDH Backbone sites. Added Grid tied Telecommunication Backbone site, Grid tied Telecommunications Access or Area Radio site, Off-grid Telecommunication Backbone site and Off-grid Telecommunications Access or Area Radio site. Updated Notes 2) and 8): Notes 2) Secondary backup power to be provided by Mobile Diesel Generators or Remote Start stationary (permanently installed) generators. A suitably rated connection facility shall be made available at site for mobile diesel generator connection. Note 8) If a Telecoms Backbone site is Off-grid, then the design would need to be approved as non-standard through the relevant technical governance committees. Updated Figure 12: Emergency Standby Power Systems single line block diagram for a Priority 1 site to display two independent power supply paths.
May 2018	1	T Jacobs	Original issue

6. Development team

The following people were involved in the development of this document:

- Alpheus Majozi
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7. Acknowledgements

Thank you to all who has provided valuable comments and inputs:

- Christine van Schalkwyk
- Malcolm van Harte
- Ayanda Ndlebe

Annex A – Reliability of m/n Active Redundant Configurations

In order to understand the effect of modular systems / active redundant systems on redundancy figures the following systems as indicated in A.1 are reviewed. It is clear that if a 10A module is replaced by two 5A modules, the system reliability is reduced. However, by adding a redundant module to the 2x5A system which results in an N+1 system (3x5A modules), the reliability of the system can be increased (99.94%) beyond that of a single 10A module (98.53%).

It is critical to understand the effect of m/n active redundancy, in order to ensure that the system reliability is not compromised. This same principle will apply in cases where required battery capacity is achieved by connecting parallel strings of battery banks. Redundant strings need to be added to achieve the same or better reliability of a single battery string with the required capacity.

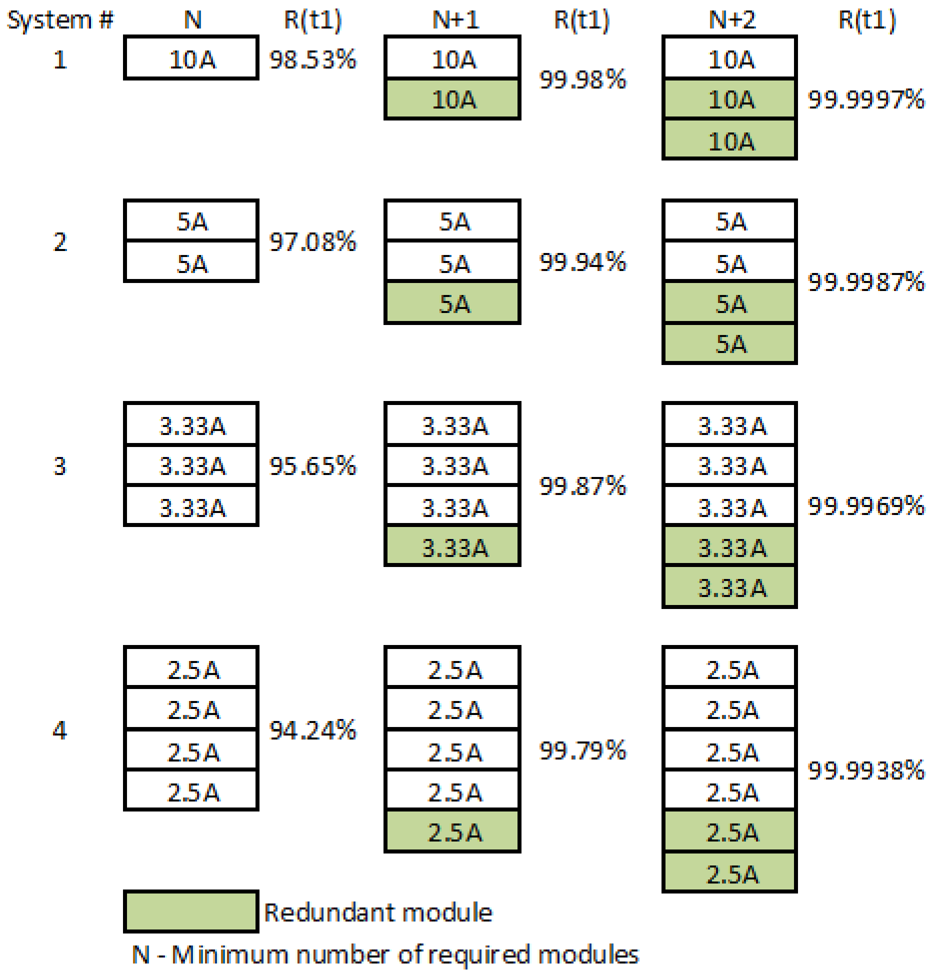

Figure A.1: Power Supply Network layout