

# Optimized MV Generator Power Plant Architectures for Large Data Centers

## White Paper 262

Revision 0

by Julien Moreau  
Malik Megdiche  
Daniel Radu

### Executive summary

For large (>5 MW) data center applications, it is common to have large generator power plants connected directly to the medium voltage (MV) electrical distribution network. The principal way to cost optimize the system is to reduce the number of generators installed using N+1 redundancy instead of 2N. This paper introduces some optimized electrical distribution architectures for the generator power plant that meets the various Uptime Institute Tier levels. A cost comparison study and reliability calculations were made on a representative case study. The results are presented in this paper. Recommendations for choosing an architecture based on the expected performance of the system are also provided.

## Introduction

For data centers larger than about 5 MW it begins to make sense to move more of the electrical distribution typically done at low voltage (LV) to the medium voltage (MV) level while also, perhaps, making the connection to the utility grid at the high voltage (HV) transmission level<sup>1</sup>. Data centers at these large power capacities have an opportunity to significantly reduce both capital and operating expenses by optimizing the design of both the electrical distribution network and how the backup power supply is connected to that network. The key optimization for doing this is going from a traditional 2N or N+1 LV generator architecture to a centralized MV generator power plant that is connected to the MV distribution network. This improved architecture is discussed in detail in this paper.

Traditionally, generators are provided in a 2N configuration to yield a high level of availability for the backup power supply. But, this comes at a high cost, both CAPEX and OPEX-wise. And since these larger data centers are connected either to redundant MV distribution feeds or to the HV transmission grid itself, the question arises as to whether 2N generator plants are required since the reliability of the grid at MV and HV is very high. Additionally, generator power plants are typically run only periodically for testing and are not used as the continuous power supply for the data center. Of course, a highly available grid does not mean that a reliable backup power supply is not required. But a 2N-based generator architecture is unnecessary especially in light of its high cost. As a result, for large data centers, N+1 (or N+2) generator architectures are becoming the reference standard design.

Since in a 2N design the generator power plant represents about 30% of the total electrical distribution investment for a data center of this size - from the connection to the grid down to the rack PDU - optimization has a significant and positive impact on the total CapEx by reducing the type and number of equipment including electrical switchboards and so on. It can also potentially improve OpEx, reduce the overall footprint, simplify the design, reduce operational risks, improve scalability, and lower carbon footprint.

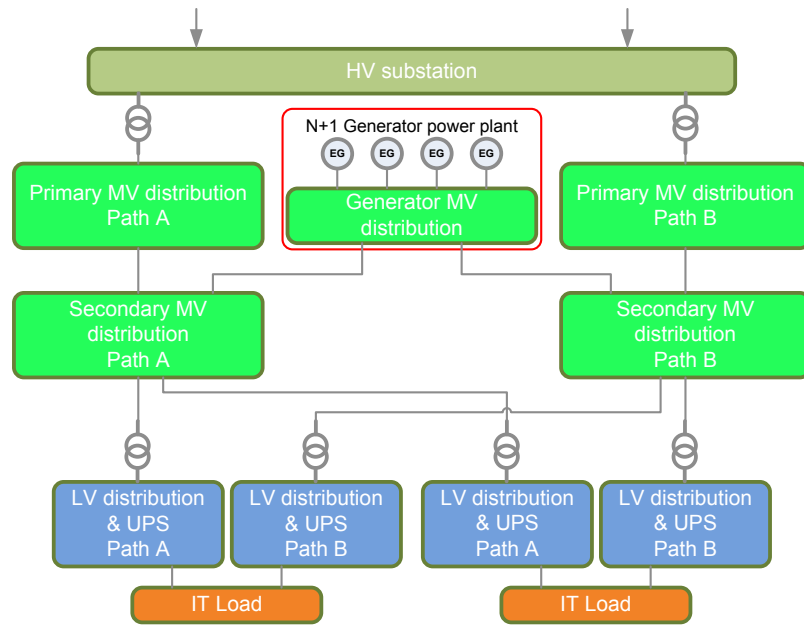
This paper will describe a globally-applicable electrical architecture using an N+1 generator power plant connected on a fully redundant MV electrical distribution (**Figure 1**). Note that the generator power plant distribution network (shown in the red box in the figure) is the focus of this paper. The overall electrical distribution network supporting the generators will be explained along with analyzing the reliability and cost of this proposed architecture. To do this, this paper will cover the following topics:

- High level description of cost and comparative cost differences of optimized MV generator power plant architectures based on the Uptime Institute's Tier levels (i.e., Tier II, Tier III and Tier IV classification)<sup>2</sup>
- A comparison of these architectures in terms of CAPEX and reliability.

<sup>1</sup> Most data centers below 1MW connect to the grid at the LV level. However, much larger data centers tend to connect to the grid at the MV and even HV level. Connection to the grid refers to where the customer-owned gear is connected to the utility-owned gear.

<sup>2</sup> Turner, W.P., J.H. Seader, V. Renaud, K.G. Brill; "Tier Classifications Define Site Infrastructure Performance." 2008, Uptime Institute, NM.

**Figure 1**  
Shows a large data center connected on the HV transmission grid. This architecture is also applicable in the case of the connection to a MV distribution grid. The IT load distribution is in 2N but block or dynamic redundancy is also applicable.



## Generator power plant architectures

The architectures described in this paper are based on the Uptime Institute’s Tier classification system. That classification system is described in **Table 1**.

**Table 1**  
Description of the Uptime Institute’s Tier levels and their implication on generator power plant architecture

Tier Level	Basic Description	Impact to Generator
Tier I	Basic capacity, no redundancy	
Tier II	Redundant capacity components (e.g., chiller, UPS, Generator)	One single failure or maintenance operation can lead to unavailability of the generator power plant.
Tier III	Tier II + concurrently maintainable (each capacity component can be maintained and/or removed without impact to IT)	Redundancy on the emergency generator and its electrical distribution equipment is needed.  One single failure can lead to unavailability of the generator power plant, but the operator is able to manually reconfigure the system no matter the fault type.  The electrical system (protection, monitoring, etc.) can be designed to help the operator manually reconfigure the system more quickly in the event of a failure
Tier IV	Tier III + fault tolerant (no single point of failure; automatic response to any failure to ensure service continuity to IT without any operator action needed)	The generator power plant is fault tolerant, without any Single Point of Failure (SPOF)*.

\* To be considered a “Tier IV equivalent” generator power plant (fault tolerant), it is necessary to take into account all operating modes when designing the system. For example, a pre-existing failure before the generators start, a failure during the starting sequence, or a failure in normal operation must all be taken into consideration and accounted for when designing the system.

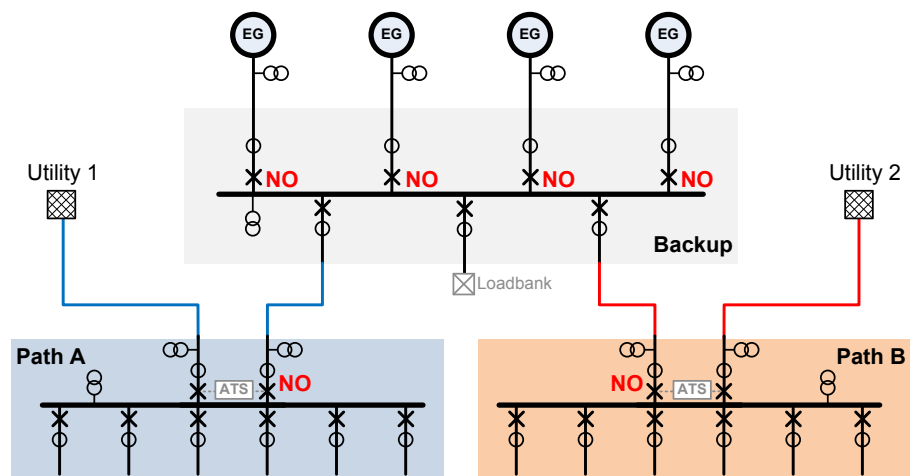
The Uptime Institute Tier classification system does not take into account the utility’s availability for evaluating designs, solely relying instead on the on-site backup equipment (i.e., emergency back-up generators, water storage, etc.).

## Tier II generator power plant architecture

To meet Tier II requirements, we propose a simple N+1 generator power plant architecture with one common MV switchboard and a basic electrical protection system (based on overcurrent and directional protection<sup>3</sup>) (Figure 2).

In this architecture, all generators are connected to a single switchboard. This “backup” switchboard supplies both paths of the data center. In the event of a major fault (e.g. something that requires switchboard or cubicle replacement) or during scheduled maintenance of the generator MV switchboard (i.e. busbar cleaning every 5 years), it is not possible to supply the data center through the generators.

**Figure 2**  
Single switchboard Tier II type architecture;  
NOTE: During normal operation with normal conditions, the switch gear is “NO” or “normally open”.



Note: The MV protection system can be designed to have discrimination between the generator incomers (input power feeds) to avoid a blackout, through use of directional overcurrent or generator differential protection. The exception would be a failure on the generator switchboard busbar.

## Tier III generator power plant type architectures

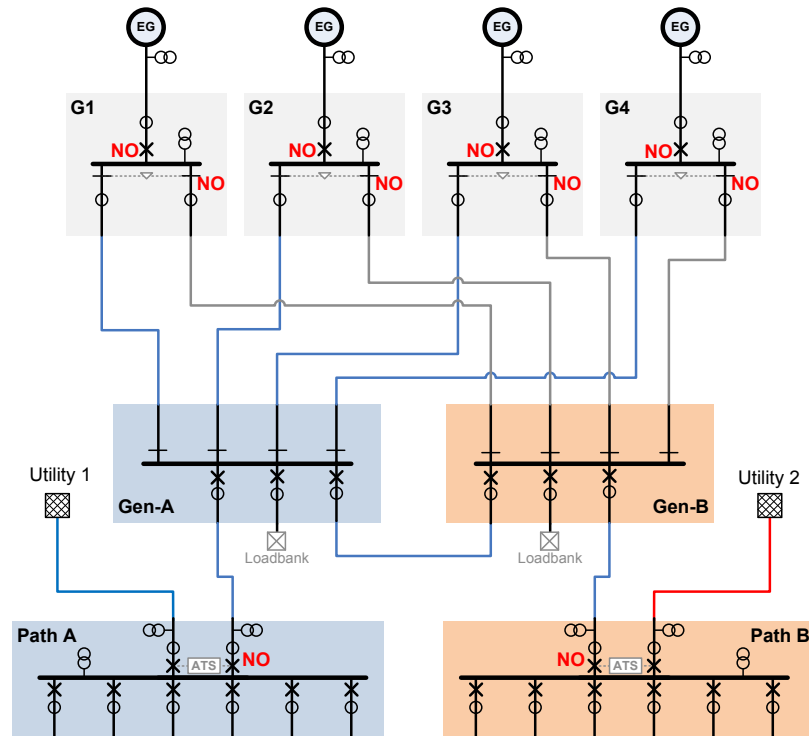
### Double-fed architecture

To meet Tier III requirements, we propose an architecture with redundant MV switchboards and a simple protection system (Figure 3). This architecture has each generator connected to both MV distribution switchboards (Gen-A and Gen-B) via two feeders. Only one of these two feeders is closed at a time to maintain a “simple” protection system (based on overcurrent and directional protection) and facilitate fault localization in case of a failure. Gen-A and Gen-B switchboards are interconnected by a coupling cable (i.e. a tie), as well as to Path-A and Path-B switchboards to be able to supply both paths even if Gen-A or Gen-B are down.

<sup>3</sup> Refer to the “Electrical Network Protection Guide”, <http://www.schneider-electric.com/en/download/document/CG0021EN/>

With a Tier III system, maintenance operation of any part of the installation (i.e., generators and the surrounding electrical equipment) will not affect the availability of the generator power plant.

In case of a failure on the power plant MV distribution (i.e. on switchgear G1 to G4, Gen-A and Gen-B, or one of the interconnection cables), the power plant will experience a blackout: however, after the fault location process, it is possible to reconfigure and restart the power plant.



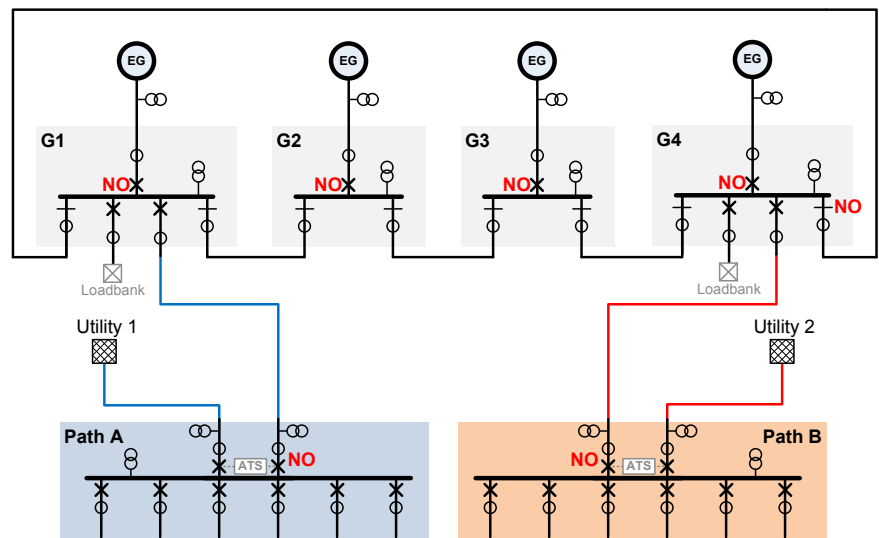
**Figure 3**  
Double-fed Tier III type architecture; NOTE: During normal operation with normal conditions, the switch gear is “NO” or “normally open”.

### Open-loop architecture

Another approach for achieving Tier III requirements is an open-loop type architecture that optimizes CAPEX (**Figure 4**). The open-loop topology allows for further simplification of the architecture as it allows for the removal of the Gen-A and Gen-B MV distribution switchboards.

Each generator switchboard can be isolated for maintenance operations. However, in the case of a failure on the power plant MV distribution (on the switchgear or a cable), the power plant will experience a blackout until a manual re-configuration to isolate the faulty electrical part is completed. To be clear, the generator power plant experiences a blackout, not necessarily the IT load itself. Note, the consequence of a generator power plant outage will depend on the downstream power distribution design and/or operating mode.

**Figure 4**  
Open-loop Tier III-  
based architecture



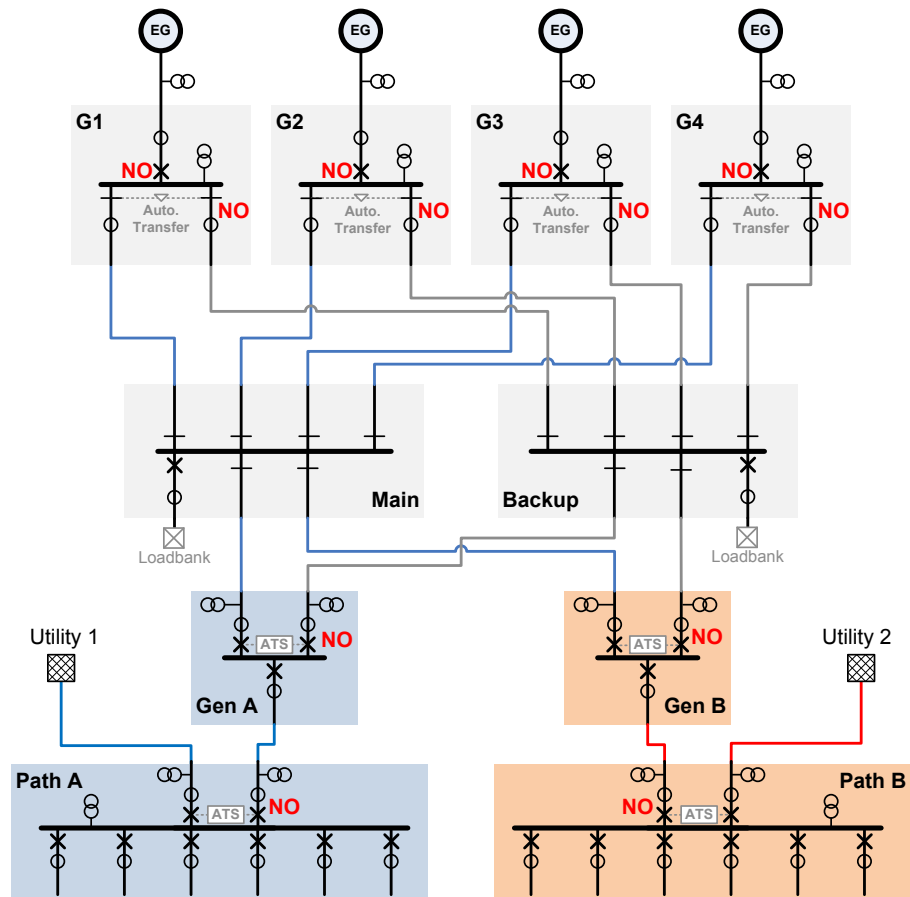
### Tier IV generator power plant type architectures

#### Double-fed architecture with automatic re-configuration

To meet Tier IV requirements, we propose a redundant MV architecture using a simple protection system with a control system for automatic re-configuration and re-starting after an electrical fault (**Figure 5**).

This architecture has each generator connected to the MV distribution switchboards (Main and Backup) via 2 feeders, but only one switchboard is supplied at a time to allow for a simple protection system (based on overcurrent and directional protection) to clear and locate faults. Each generator switchboard (G1 to G4) has an automatic control system (e.g., PLC) that can switch its feeder and supply either the Main or the Backup switchboard.

The Main and Backup switchboards supply the Gen-A and Gen-B MV switchboards. On these last switchboards, an ATS (Automatic Transfer System) is installed that can choose the energized upstream switchboard (Main or Backup).



**Figure 5**  
*Double-fed with automatic re-configuration Tier IV type architecture*

For this architecture, availability depends on the control system's capacity to restart after failure. To avoid a single point of failure (SPOF), redundant and independent controllers are required.

Because this design requires a basic open transition changeover between utility and generator, the ATs on the Gen-A and Gen-B switchboards should be a simple, independent, and standard ("off the shelf") product or solution.

The generator switchboard controllers will be customized based on the specific system architecture and shall meet Tier IV requirements to avoid creating any single point of failure.

Note: All failure cases must be taken into account by the control system to avoid a SPOF: pre-existing fault, failure on one generator switchboard, failure during starting sequence, etc.

### Closed-loop architecture

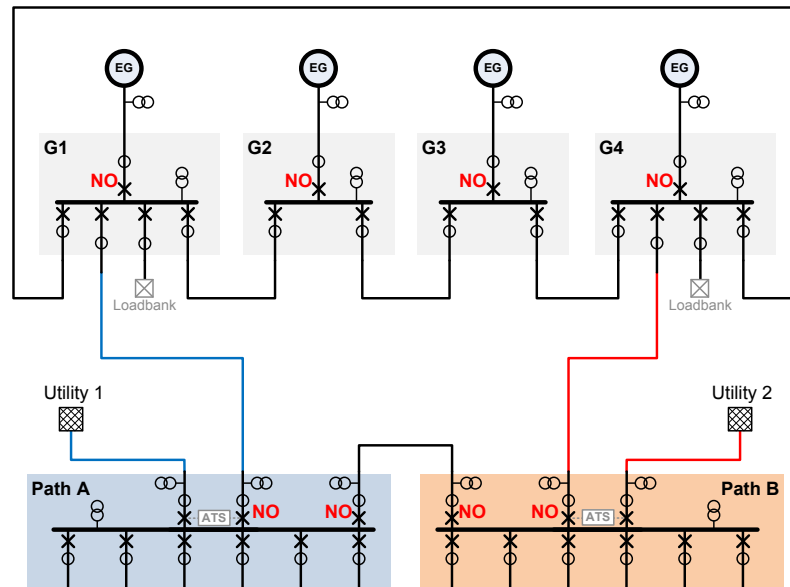
A preferred Tier IV-based architecture would be a fault-tolerant, cost optimized, closed-loop architecture, which uses a differential protection system without needing a control system (**Figure 6**).

This architecture reduces the amount of MV equipment needed compared to the previous Tier IV architecture. No control is necessary on the MV distribution in the event of a failure. The protection system is enough to ensure service continuity. For this architecture, the differential protection system is strongly recommended: bus-bar differential protection (87B) on each switchboard with line differential protection (87L) on each cable between these switchboards and the main feeder. This makes

it easy to locate the fault and trip only the faulted zone. Whatever the fault position is, the service continuity is ensured.

The line differential protection is not commonly used in MV installations and the design (including specification of CTs, selection of settings, etc.) requires careful consideration to ensure selective operation for both phase and earth faults. The protection relays that ensure this type of protection system are more commonly used for HV transmission grid applications, where they help to achieve a high reliability level ensuring the selectivity and the service continuity even in case of protection system failure such as when the breaker fails to trip, CTs or VTs failure, etc.

**Figure 6**  
Closed-loop Tier IV type  
architecture



Note: The use of a directional protection system with logic discrimination is not appropriate for this architecture because the discrimination cannot be ensured during the starting sequence in the event of a pre-existing fault (3-phase fault). This will lead to a single point of failure.

Note: An open loop architecture with an automatic reconfigurator could be regarded as a Tier IV type architecture. However, the automatic reconfigurator could be considered to be a single point of failure (SPOF). And to automatically locate the fault efficiently no matter the conditions (pre-existing fault before power on, fault during starting sequence, etc.), it is necessary to use a complex protection system that uses differential protection along with a backup protection system. The protection system is actually the same protection system used in closed loop distribution, **so for a Tier IV type system the use of a closed loop architecture is recommended.**

## Architecture cost comparison study

### Assumptions

For the cost comparison of the different architectures presented in the previous section, we used the following assumptions:





- Electrical distribution voltage: 11 kV
- Genset nominal power: 2500 kVA
- Case 1: generator power plant configuration has 4 gensets



- Case 2: generator power plant configuration has 9 gensets
- Short-circuit current withstand (IEC): ≤ 20 kA, ≤ 25 kA, and ≤ 31.5 kA

The price comparison used in this document includes the MV switchgear, the MV cables, and the installation. This comparison is only focused on the generator power plant distribution network.

The different equipment considered for this study include the following Schneider Electric gear:

MV Switchboards			Protection relays
			
<b>SM6</b> <b>≤20kA</b>	<b>Premset</b> <b>≤25kA</b>	<b>PIX</b> <b>≤31.5kA</b>	<b>SEPAM</b>  <b>Easergy MiCOM 40 series</b>

### Results and conclusions

**Table 2** gives a per unit cost **comparison** of the different architectures. The most economical configuration (Tier II, <20kA, and highlighted in darker gray) is used as a reference base point for each comparison (4x or 9x generators):

**Table 2**  
*Shows the relative MV switchgear and cabling price difference between the different architectures*

Price comparison of switchgear & cables		4x Generators			9x Generators		
		<20kA SM6	<25kA Premset	<31.5kA PIX	<20kA SM6	<25kA Premset	<31.5kA PIX
Tier II Generator power plant		1.0	1.2	2.0	1.0	1.2	1.8
Tier III generator power plant	Double-fed	2.5	3.3	6.3	2.8	3.9	7.1
	Open loop	2.0	2.4	4.2	2.9	3.8	5.1
Tier IV generator power plant	Double-fed automatic	3.4	4.2	7.4	3.4	4.9	7.9
	Closed loop	2.4	2.8	4.5	3.5	4.6	5.6

There are some key takeaways from this comparison:

- Tier II is the least expensive configuration, not surprisingly.
- By moving from a Tier II to a Tier III type architecture, the cost of the MV distribution is multiplied by 2 to 4 times depending on the architecture chosen.
- The gap between Tier III and Tier IV is much lower (see note below), between 10% and 30%.

- The loop topology, open or closed, in most cases allows for a cost saving of 20% on average (up to 40% maximum) while also reducing the footprint which might be important in some cases (note figures are not presented here).
- As shown in this comparison the short circuit current has an important impact on the MV electrical distribution cost, not only for the generators power plant but for the overall data center MV distribution as well. The difference is +27% on average when you go from 20 kA to 25 kA, and +61% on average going from 25 kA to 31.5 kA.

Note: The figures above are only related to generator power plant electrical distribution which represents 2% to 6% of the overall cost of the data center electrical infrastructure. The principal savings gained by going from a 2N to N+1 generator architecture (i.e., the generators themselves) is not quantified here.

## Reliability & availability analysis

Ensuring high reliability and availability of the server power supplies is the key objective for the data center physical infrastructure systems:

- reliability is the probability of not having a failure in the supply of power to any IT rack during a given period of time;
- availability is the percentage of time where the IT racks are powered.

Since even the briefest of outages can have severe effects on the business, customers usually define their reliability target as “no risk of power supply failures”. Therefore, the customer target is usually more related to the reliability rather than the availability. However, some customers hosting their IT process across several data centers are able to handle a single data center shutdown. They tend to be more interested in the availability of each of their data centers. These customers can formulate their target as “data center availability > 99,999%” (or in number of nines). Considering these customer inputs, the computed reliability and availability indexes are

- the mean failure frequency (estimated number of failures per year) which reflects the reliability of the data center infrastructure,
- and the mean unavailability (estimated percentage of the time where the data center is unavailable).

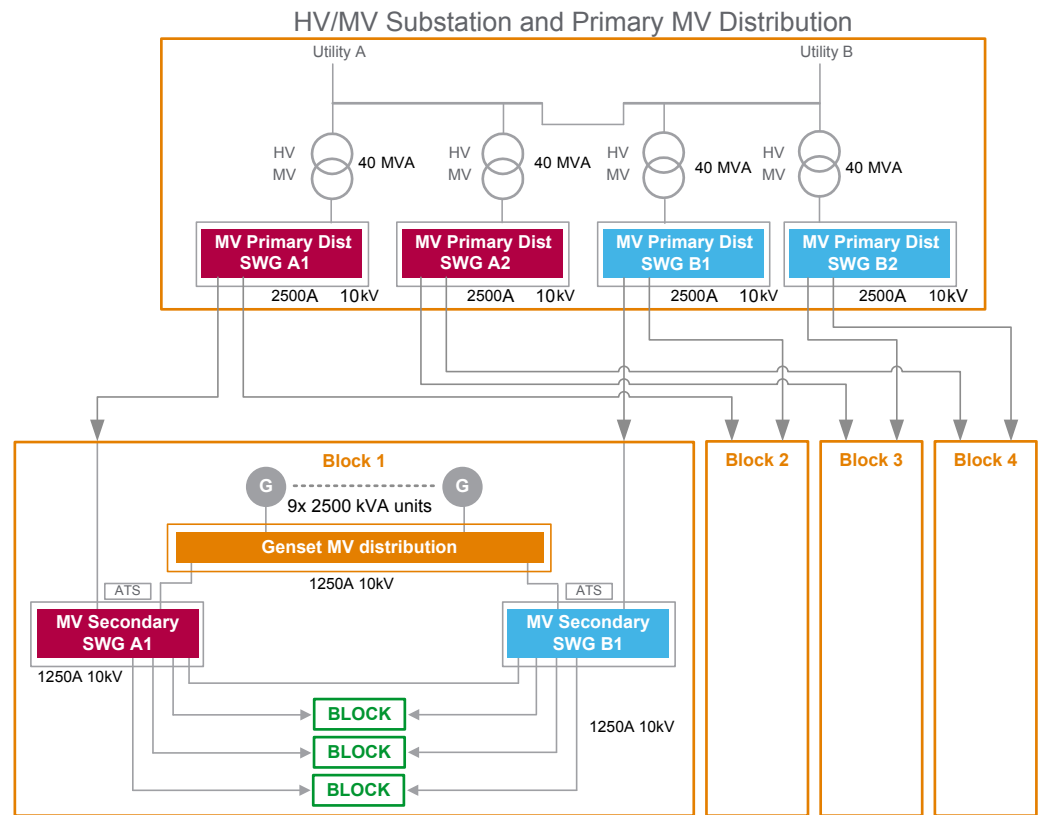
### Scope of the availability and reliability study

The presented reliability and availability study aims to show the difference in terms of reliability performance between several generator power plant distribution architectures when designing a full redundant architecture as shown in **Figure 1**.

The study is focused primarily on the generator power plant MV distribution system. While there are other components that could also cause loss of IT load (e.g., LV transformers, LV switchgear, etc.), the portion of the system downstream of the MV Secondary Distribution is assumed to be identical in each of the options considered. Focusing only on the generator switchgear allows for evaluation of the relative performance of each MV architecture. This reliability and availability study is based on a data center infrastructure composed of four main blocks each supplied by 2 redundant A & B MV switchboards as shown in **Figure 8**<sup>4</sup>.

<sup>4</sup> RD102DS (Reference Design 102): 46 MW (IEC), Chilled Water, 40000 m2 (2015)

**Figure 8**  
Data center infrastructure  
used in the reliability  
study



The HV/MV substation is designed to provide redundancy by having:

- two redundant HV overhead lines;
- two redundant sets of two HV/MV transformers;
- a high voltage Air Insulated Substation (AIS) with a single busbar and a tie circuit breaker
- the auxiliaries of the substation (e.g. protection relays, PLC, closing/opening coils) are designed to provide no common mode failure of the entire HV/MV substation.

The MV distribution consists of :

- MV distribution from the HV/MV substation designed with a 2N architecture using an AIS technology;
- each block's MV switchboard, equipped with two incomer circuit breakers with an ATS function, nine feeder circuit breakers, and a normally open tie circuit breaker.

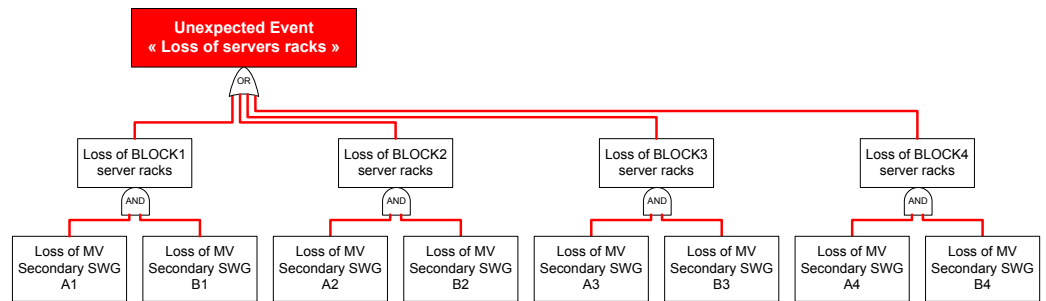
The emergency power plant consists of:

- 9 generators with monthly load bank tests;
- medium voltage distribution from the generators to path A & path B MV switchboards using AIS technology;
- a master PLC managing the main power plant control with hot-standby redundancy; all redundant equipment is assumed to be physically separated to minimize common mode failures.

## Data center “unexpected event” definition

The “unexpected event” is defined as “the loss of power to server racks in either block 1, 2, 3, or 4” as shown in **Figure 9**.

**Figure 9**  
Data center unexpected event definition



The study is performed using a failure mode and effect analysis (FMEA) combined with a fault tree analysis for multiple contingency analysis. As this reliability study needs accurate results to be able to compare the different emergency power plant architectures, the calculations take into account:

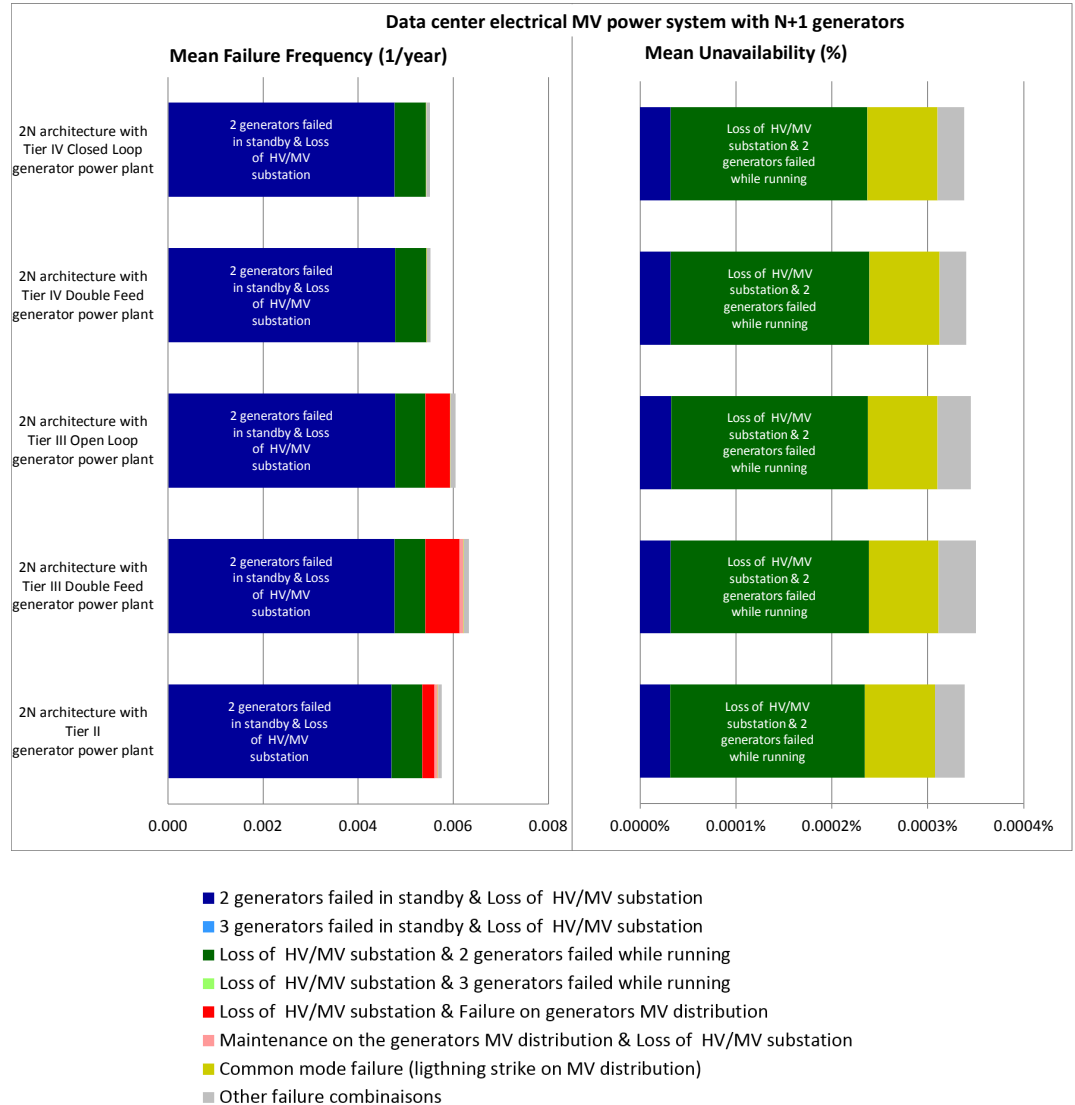
- all equipment failure rates according to field experience data
- all equipment failure modes
- all time elements including detection time of the failure, the diagnostic time according to the equipment damages, the spare parts delivery time, and the repair time
- all scheduled maintenance operations and periodic tests

The equipment reliability and maintenance database shown in **Figure 10** is based on field experience of manufacturers and end-users (see the Appendix). Note that each generator set includes the engine, the alternator, the starting system, the cooling system, and the control system, but not the piping distribution (diesel tank, piping system, pumps) from the tank to each generator unit.

The common mode failure coming from an overvoltage caused by a severe lightning impact has also been taken into account:

- Severe lightning impact on the HV equipment of the HV/MV substation that damages the redundant HV/MV transformers is estimated at 1% (risk that the lightning impact is over the surge protection capability) of the HV lightning impact risk
- Severe lightning impact on the MV equipment of the HV/MV substation that damaged the redundant MV/LV transformers is estimated at 1% (risk that the lightning impact is over the surge protection capability) of the MV lightning impact risk

## Reliability and availability performance for an “8+1” generator power plant



**Figure 10**  
 Reliability and unavailability estimation considering the unexpected event “the loss of server racks in block 1, 2, 3, or 4” for the data center architecture with “N+1” emergency generators

The results in **Figure 10** show that for N+1 generators, the mean failure frequency and mean unavailability remain about the same no matter which emergency generator power plant MV distribution architecture is chosen:

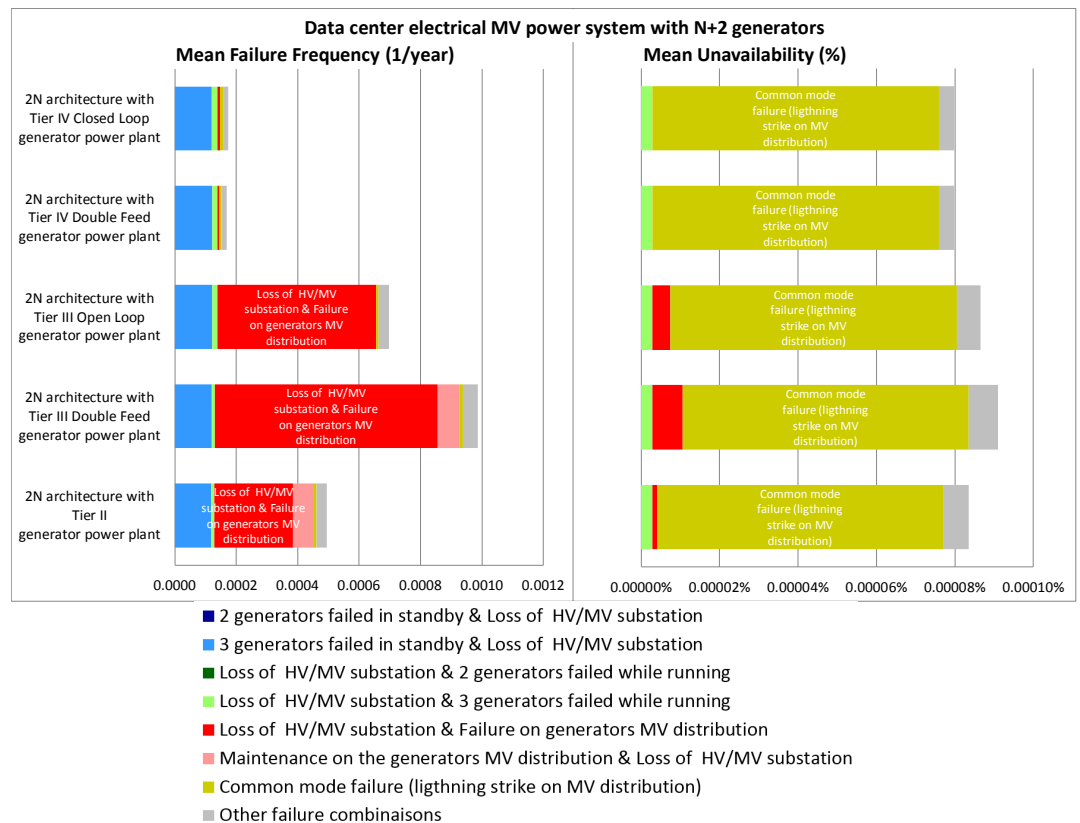
- The mean unavailability is about:
  - 0.00035% for all architectures, which is equal to 99,99965 % availability or “five nines” of availability.
- the mean failure frequency is about 0.0055 failures per year;
  - it means that the site will experience about 1 failure every 180 years
  - it means that the site has a 1/20 chance of experiencing a failure in 10 years

The main failure sequence that leads to the data center being shutdown is “loss of the HV/MV substation and loss of 2 generators units”. The MV architecture of generator power plant is not a significant contributor to the data center downtime. That is

why the availability and reliability levels remain the same no matter which MV distribution architecture is chosen for the generator power plant.

This level of reliability and availability can be acceptable for many critical applications. However, if some customers require a still higher level of reliability, the generator power plant should be designed with “N+2” redundant generator units.

## Reliability and availability performance for a “8+2” generator power plant



**Figure 11**  
 Reliability and unavailability estimation considering the unexpected event “the loss of server racks in block1, 2, 3, or 4” for the data center architecture with “N+2” emergency generators

The results in **Figure 11** show that the MV power supply for the IT load has been greatly improved by increasing the generator plant redundancy:

- the mean unavailability is about:
  - 0.00008 % for all architectures, which corresponds to 99,99992 % availability (six nines availability).
  - The availability remains the same regardless of the emergency generator power plant used because the majority of the unavailability is caused by the common mode failure “lightning impact on the MV equipment of the HV/MV substation”.
- the mean failure frequency is about:
  - for the architecture with a Tier II generator power plant, 0.0005 failure per year which represents a failure probability over 10 years of 1/200
  - for the architecture with a Tier III generator power plant, 0.001 failure per year which represents a failure probability over 10 years of 1/100

- for the architecture with a Tier IV generator power plant, 0.00018 failure per year which represents a failure probability over 10 years of 1/550

The 2N architecture with a Tier II generator power plant has a high level of reliability and should be considered as sufficient, particularly if the other parts of the overall system are considered (LV equipment, mechanical system, other common mode failures and also human factor).

For this architecture, the failure sequence “Loss of the HV/MV substation and failure on the generators MV distribution” represents more than 50% of the data center shutdown frequency. That is why there is a potential for improvement by designing more redundancy into the generator MV distribution network.

The idea of the Tier III generator power plant architectures is to be able to reconfigure the MV generator distribution system in case of a failure on the upstream MV distribution. However, as shown in the reliability and availability estimation, these architectures do not provide any improvement in reliability because:

- more MV distribution equipment means more potential failures
- as these failures are only detected when the power plant is running, a failure on the generator MV distribution will last for a long time before the generator MV distribution is manually reconfigured
- the gain of having a reconfigurable power plant capability is lost when considering the unavailability of the power plant electrical distribution in standby mode (the generator electrical distribution is unavailable, but the failure will only be detected when the power plant distribution is energized)

The best way to improve reliability beyond that of the fully redundant architectures with a Tier II generator power plant is to move to a fully redundant architecture with a Tier IV generator power plant.

Note: some Tier III backup generator power plant architectures could be designed to keep the generator power plant electrical distribution under live operating conditions during normal operation to be able to immediately detect the MV generator electrical distribution fault. However, as that would result in higher cost and control system complexity, the Tier IV architectures are recommended in this case.

## Reliability analysis outcomes

Price comparison of switchgear & cables		Full redundant architecture with N+1 Generator power plant		Full redundant architecture with N+2 Generator power plant	
		Failure probability	Availability	Failure probability	Availability
Tier II Generator power plant		1/20	99.999%	1/200	99.9999%
Tier III generator power plant	Double-fed	1/20	99.999%	1/100	99.9999%
	Open loop	1/20	99.999%	1/100	99.9999%
Tier IV generator power plant	Double-fed automatic	1/20	99.999%	1/550	99.9999%
	Closed loop	1/20	99.999%	1/550	99.9999%

**Failure probability:** Probability to have a failure over the next 10 years.

The key takeaways are:

- While the Tier classification system describes the expected redundancy level of the generator power plant, it is necessary to perform a reliability and availability analysis to understand the likely reliability performance of the generator units and electrical distribution
- Availability may be the most commonly-considered criterion, but reliability (IT rack shutdown mean frequency index) is also a key value (for data center applications typically).
- The redundancy levels of the electrical sources should be compared to other parts of the data center (LV power distribution, cooling system, etc.) to avoid designing in redundancy where it is not needed.
- During the design phase of a data center architecture, the first step is to design the appropriate redundancy for the generators before addressing the redundancy of the electrical distribution of the generators.

Fully redundant architectures with a Tier II generator power plant can be acceptable for extra large data centers in terms of reliability and availability:

- Tier II power plant with N+1 generators gives an availability of 5 “nines” and a failure probability of 1/20 over 10 years of operation.
- Tier II power plant with N+2 generators gives an availability of 6 nines and a failure probability of 1/200 over 10 years of operation.

To reach a higher level of performance, a Tier IV generator power plant is recommended since the Tier III power plants described in this study are less reliable than the Tier II power plant (same availability, but higher failure rate).



## Conclusion

For larger data centers with a fully redundant architecture, backup power supply systems are often deployed at the MV level, which reduces cost by centralizing the generator sets. The main means to optimize cost and simplify these large generator plants is to use N+1 genset redundancy instead of 2N, and moreover the electrical architecture must be properly designed to maintain a high level of reliability. This paper proposes several optimized generator power plant architectures based on the Uptime Institute's various Tier levels. This white paper gives a comparison in terms of cost and reliability.

Since the electrical distribution network has a high reliability level, the first step then is to study the reliability of the generator sets themselves including their controllers and to define the adequate generator redundancy level (N+1, N+2, etc.) per the expected performance. The backup power plant MV distribution design should be chosen based on that.

Given the results of the study, a large data center with redundant electrical distribution supplied by a reliable utility source and a Tier II generator power plant achieves a reliability level which might be acceptable for large data centers at a cost less than the other architectures described in this paper. To obtain an even higher level of performance, the recommendation is to move directly to the Tier IV generator plant architectures as the Tier III generator power plant architectures presented in this paper are less reliable than the Tier II generator power plant architecture and have a cost relatively close to the Tier IV generator power plant architectures. Note also, in most of the cases the loop topology, open or closed, allows significant cost and footprint savings.

### About the authors

**Julien Moreau** received his masters degree in electrical engineering in 2007 from the “Conservatoire National des métiers” (CNAM) of Aix-en-Provence, France. He joined Schneider Electric in 2004 where he spent several years in the magnetic and thermal expertise team for new products and equipment development and three years in the shore connection program. Julien is currently a power system expert dedicated to large data center applications since 2013. His interests include large data center applications, protection systems, shore connection systems, LV and MV equipment, and system design. He holds several patents linked to frequency conversion substation.

**Malik Megdiche** received his Master of Science degree and his PhD in Electrical Engineering from the National Polytechnic Institute of Grenoble (INPG) in 2001 and 2004. He is presently a power system engineer and reliability expert in Schneider Electric company. His main fields of interest are medium and low voltage power system design, protection, simulation and reliability assessment.

**Daniel Radu** was born in 1975 in Bucharest, Romania. He obtained a Ph.D. degree in Electrical Engineering, in 2004, from the University “POLITEHNICA” of Bucharest, Romania. From 1998 to 2002 he has been assistant professor of Electrical Engineering in the same University. Follow this was involved in research and teaching activity with Power Engineering Laboratory of Grenoble – LEG, France. He is currently with Schneider Electric, France, since 2006. His interests include shore connection systems, large data center applications, low and medium voltage power systems transient analysis, power systems modelling, LV and MV equipment and system design. He published more than 30 international papers in conferences proceedings and journals and several white papers in the field of Electro-Intensive Applications. He holds several patents in the field of power quality, frequency conversion applications and power systems. Also he participates as technical expert to TC18 & TC23 committees of IEC and is IEEE member.

# Appendix: Reliability and maintenance data


EQUIPMENT	FAILURES			SCHEDULE MAINTENANCE OPERATION			
	FAILURE MODE	DATA SOURCE	MEAN TIME TO REPAIR (including spare parts delivery time) (h)	MAINTENANCE OPERATION	ZONE LOCKED OUT	FREQ. (1/yr)	MEAN DOWN TIME (h)
HV utility substation with 2 redundant HV overheadlines	Major HV blackout		0.5				
	Very long interruption	Field experience french utility	0.978				
	Long interruption (> 3min)		0.127				
HV overhead line (per km)	Momentary	Field experience french utility	4.2.E-03				
	Permanent		8				
HV/MV transformer	Minor insulation breakdown		2160	Schedule maintenance - Each equipment is locked out for cleaning operation once a year - Annual checking operation on disconnectors and surge protection - Annual protection check on HV protections - Major overhaul maintenance on HV circuit breakers each 10 years			
	Major insulation breakdown		8760				
	Auxiliaries		24				
HV AIS Circuit breaker	Insulation breakdown		377				
	Spurious trip		178				
	Fail to open / close		208				
HV AIS disconnecter	Other		48				
	Insulation breakdown		372				
	Fail to open / close		178				
HV AIS earthing switch	Other		12				
	Insulation breakdown		372				
	Fail to open / close		178				
HV AIS CT	Other	Field experience on AIS / GIS HV substation (Cigré, JST, EDF)	12				
	Insulation breakdown		192				
	Other		12				
HV AIS VT	Insulation breakdown		185				
	Other		4.8				
HV AIS Busbar	Insulation breakdown		216				
	Other		12				
HV AIS Termination	Insulation breakdown		192				
	Other		24				
HV AIS cable junction box	Insulation breakdown		192				
	Other		24				
HV AIS transformer connexion	Insulation breakdown		192				
	Other		24				
HV AIS surge protection	Insulation breakdown		180				
MV cables (per meter)	Insulation breakdown	IEEE Gold Book	62				
MV CB cubicle - withdrawble type	Busbar insulation breakdown		728		Switchboard busbar compartment maintenance (connections, isolation test, cleaning)	Switchboard	0.2
	Cubicle insulation breakdown		728	Cubicle maintenance	Cell	0.2	0.5
	Improper opening	Schneider Electric Field Experience	168	Circuit breaker maintenance	Cell	0.2	1
	Fail to open on fault		168	Opening/Closing operation	Cell	1	
	Fail to open on demand		168	Protection relay test	Cell	0.2	0.5
	Minor which requires to power down to be repaired		168				
Emergency groups	Fail to start	Detailed Study of Emergency Diesel Generator Performance Using EPIX/RADS Database ANS PSA 2008 Topical Meeting S. A. Eide, T. E. Wierman, D. M. Rasmuson September 2008	56	Inspection, checks, equipment replacement	Generator unit	3.3	6
	Fail to run		56	On load test with the load bank		12	
	Short-circuit output		56				
PLC for automatic changeover automation	No Action	Schneider Electric Field Experience	36	Test		12	
	Unintended Action		36				


“Emergency groups” data from “Detailed Study of Emergency Diesel Generator Performance Using EPIX/RADS Database ANS PSA 2008 Topical Meeting” S. A. Eide, T. E. Wierman, D. M. Rasmuson September 2008



 [Medium Voltage Technical Guide](#)

 “Detailed Study of Emergency Diesel Generator Performance Using EPIX/RADS Data-base ANS PSA 2008 Topical Meeting” S. A. Eide, T. E. Wierman, D. M. Rasmuson, September 2008

 [Browse all white papers](#)  
[whitepapers.apc.com](http://whitepapers.apc.com)

 [Browse all TradeOff Tools™](#)  
[tools.apc.com](http://tools.apc.com)

## Contact us

For feedback and comments about the content of this white paper:

Data Center Science Center  
[dcsc@schneider-electric.com](mailto:dcsc@schneider-electric.com)

If you are a customer and have questions specific to your data center project:

Contact your Schneider Electric representative at  
[www.apc.com/support/contact/index.cfm](http://www.apc.com/support/contact/index.cfm)