Base Load Power Hub (BLPH)

UPS & BATTERY SIZING CALCULATIONS

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1 INTRODUCTION

1.1 PROJECT OVERVIEW

Crosswind, a Shell and Eneco joint venture, was awarded the tender to develop the offshore Hollandse Kust Noord (HKN) wind farm, located 18.5km off the coast of Netherlands near the town of Egmond aan Zee. The consortium plans to have HKN operational in 2023 with an installed capacity of 759MW generating at least 3.3TWh per year. This is sufficient renewable power to supply more than 1 million Dutch households with green electricity.

Offshore wind farms produce intermittent electricity and balancing these dips and peaks and integrating this electricity into the national energy system requires new technologies. For this reason, the offshore wind farm will include several new technologies that could be implemented at full-scale in the future. The new technologies being explored include a floating solar park, a short-duration battery storage as well as long-term storage via green hydrogen produced by water electrolysis and subsequently consumed in a fuel cell. The combination of these individual measures, herein referred to as the Base Load Power Hub (BLPH) will ensure a continuous power supply regardless of the wind situation.

1.1.1 Project Location

The Hollandse Kust Noord (HKN) wind farm is located 18.5km off the coast of the Netherlands near the town of Egmond aan Zee.

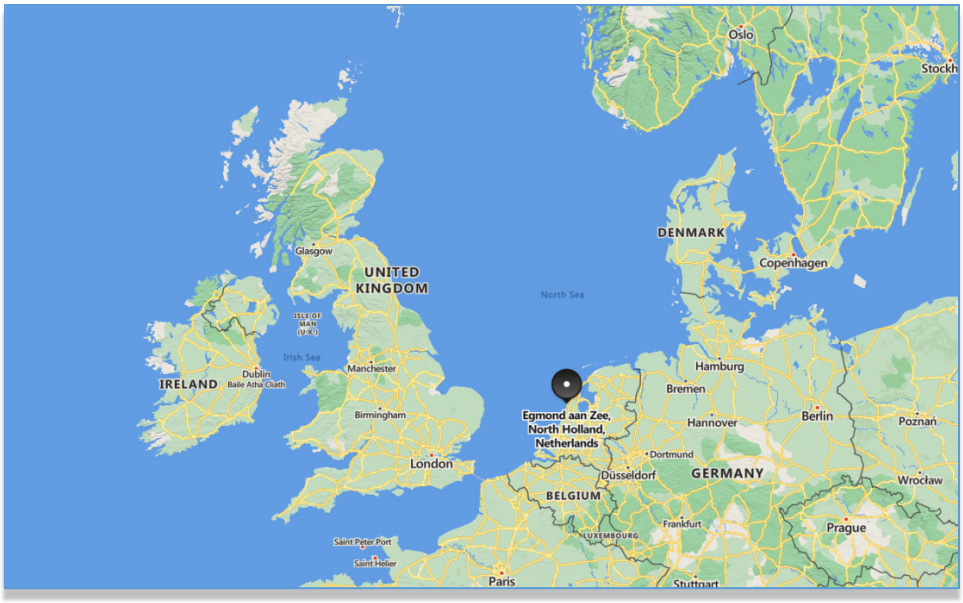


Figure 1 HOLLANDSE KUST NOORD WIND PARK Location Map

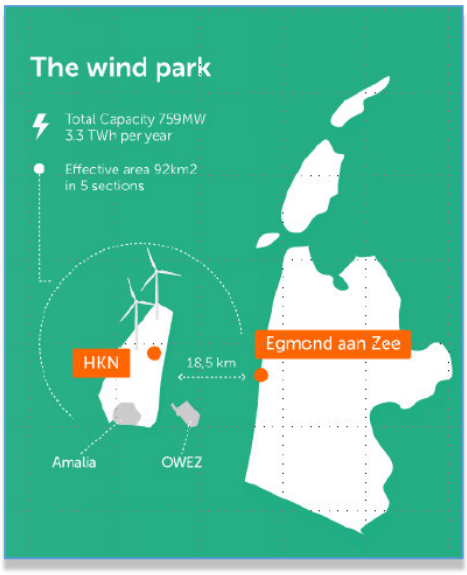


Figure 2 - Wind Park Details

The wind farm will consist of No. 69 x 11.5MW wind turbine generators each to be installed on a dedicated monopile structure. A 70th monopile located on coordinates E 590719.1, N 5841602.3 is reserved for installing the platform accommodating the BLPH. The monopile structure was designed and installed by Van Oord Offshore Wind (VooW) and therefore not part of the BLPH scope.

1.1.2 Project Concept

All components included in the BLPH will be integrated onshore on a topsides and installed in an offshore location within the boundaries of the HKN wind farm. At its simplest, the BLPH will store energy during periods of high electricity generation from renewable sources (a wind turbine generator and the floating solar PV farm) and release it during periods of low generation. In practice. It is expected that the energy stored will supplement generation from renewable sources to ensure that at least 1.0MW of power is exported to the electrical grid regardless of wind/solar availability.

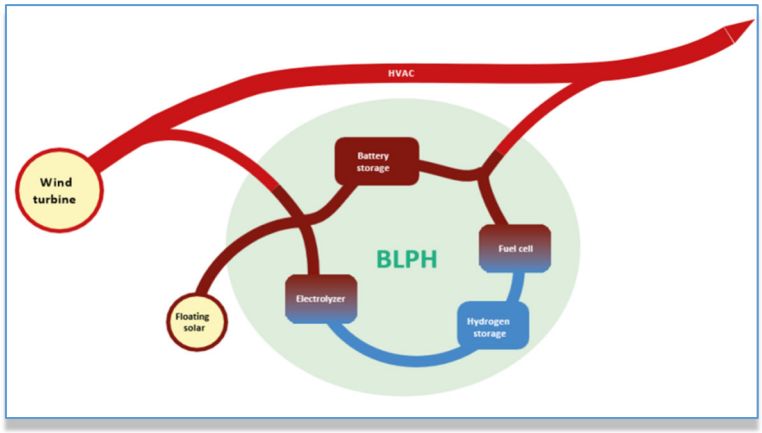


Figure 3 – BLPH Concept

Electricity in the BLPH will be stored in the form of electrons in a battery energy storage system (BESS) as well as converted into green hydrogen via water electrolysis. When the power output from the connecting wind turbine drops to below 1 MWe, the BLPH will return its stored energy to supplement the remaining power output. This will be by discharging the BESS, while stored hydrogen will be converted back into electricity using a fuel cell to extend the discharge duration.

The purpose of the BLPH s to function as a testbed for the integration of energy storage technologies with renewable generation. It is expected that equipment installed on the BLPH will operate as Normally Unmanned Installation for at least two (2) years with no or minimal maintenance and it will have its own independent control room with the ability to communicate with Crosswind's control room.

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2 DOCUMENT SCOPE

This scope of this UPS & Battery sizing calculations is to determine the following:

1. The kVA capacity of AC UPS and DC UPS to power the connected loads.
2. The duty cycle and ampere-hour (Ah) capacity of batteries for the AC UPS & DC UPS.

2.1 REFERENCES

Doc. No.	Description
123A90-DDL-EL-LIS-20016	Electrical Load List & Balance (CCS MODE 'IMPORT')
123A90-DDL-EL-SP-20031	Technical Specification, IDS and DDS for AC UPS System
123A90-DDL-EL-DS-20032	Technical Data Sheet (TDS) for AC UPS System
123A90-DDL-EL-SP-20035	Technical Specification, IDS and DDS for DC UPS System
123A90-DDL-EL-DS-20036	Technical Data Sheet (TDS) for DC UPS System
123A90-DDL-EL-SP-20085	Technical Specification for Electrical Requirement in Packaged Units
123A90-DDL-EL-DG-20160	Electrical Single Line Diagrams AC UPS Systems
123A90-DDL-EL-DG-20161	Electrical Single Line Diagrams DC UPS System
123A90-DDL-EL-LIS-20165	Electrical Schedules (Distribution Boards, AC UPS, DC UPS, etc.)

Table 1 - Reference Documents

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2.2 DEFINITIONS AND ABBREVIATIONS

COMPANY or Client (CPY):	CROSSWIND
CONTRACTOR (CTR):	ROSETTI MARINO S.p.A.
PROJECT:	HOLLANDSE KUST NOORD WIND PARK Project
INSPECTION AUTHORITY:	The organization representing the Owner or Vendor /Contractor that verifies that the equipment and facilities have been designed, constructed, inspected and tested in accordance with the requirements of this specification and the Purchase Order/Contract.
INSPECTOR:	A qualified individual representing the Owner, Vendor/Contractor or the assigned Inspection Authority, who verifies that the equipment and facilities have been designed, constructed, inspected and tested in accordance with the requirements of this specification and the Purchase Order/Contract.
VENDOR:	Individual, firm or manufacturer that provide Materials/Equipment to COMPANY in accordance with this specification and terms of the Purchase Order.
AC / DC:	Alternating current / Direct current
Ah:	Ampere-hour
BESS:	Battery Energy Storage System
CB:	Circuit Breaker
CCS:	Central Control System
DCS:	Distributed Control System
EMCS:	Electrical Monitoring & Control System
HVAC:	Heating Ventilation and Air Conditioning
HV/MV:	High Voltage / Medium Voltage
I/O:	Input / Output
LV:	Low Voltage
PAS:	Process Automation System
SIS:	Safety Instrumented System
kVA:	Kilo Volt Ampere (apparent power)
kW:	Kilo Watt
UCP:	Unit Control Panel
UPS:	Uninterruptible Power Supply

Table 2 - Definitions and Abbreviations

3 APPLICABLE CODES AND STANDARDS

The following documents list shall constitute an integral part of this specification.

IEC - International Electro technical Committee & IEEE (latest edition shall be applied).

- IEC 62040 Uninterruptible power systems (UPS) (as applicable).
- IEC 60623 Secondary cells and batteries containing alkaline or other non-acid electrolytes – Vented nickel-cadmium prismatic rechargeable single cells.
- IEC 60896 Stationary lead-acid batteries.
- IEC 61000 Electromagnetic compatibility (EMC) (as applicable).
- IEC 61892 Mobile and fixed offshore units – Electrical installations.
- IEEE 485 IEEE Recommended Practice for Sizing Lead-Acid Batteries for Stationary Applications
- IEEE 1115 IEEE Recommended Practice for Sizing Nickel-Cadmium Batteries for Stationary Applications
- DEP 33.64.10.10-Gen DEP Specification – Design and Engineering practice

4 ENVIRONMENTAL AND OPERATING CONDITIONS

The Metrological and Oceanographic Data are as given below (source: HKN2018 data @ 1979-2018)

Description	Value	Unit
Ambient Conditions		
Ambient Temperature (min/nom/max) – hourly @ +10m	-8.4 / 10.5 / 25.0	° C
Atmospheric Pressure (nominal) – hourly @ +10m	1013.7	mbar
Specific Humidity (min/nom/max) – hourly @ +10m	4.2 / 6.5 / 9.5	x 10^{-3}
Wind conditions		
Annual average wind speed (at 100m)	9.56	m/s
Extreme Wind Speed for 1-Year Recurrence Period (at 100 m)	33.1	m/s
Extreme Wind Speed for 50-Year Recurrence Period (at 100 m)	41.0	m/s
Marine conditions		
Sea Water Temperature (min/max)	1.2 / 20.2	° C
Average Sea Water Density	1025	Kg/m^3

Table 3 - Metrological and Oceanographic Data

5 ELECTRICAL SYSTEM

The A.C. main power supply characteristics (e.g. voltage, frequency, and voltage and frequency variation) shall be defined in the relevant data sheet.

The following voltage levels shall generally be used where technically possible:

Service	Rated AC Voltage (Volts)	Phase / Wire	System Earthing
LV supply	400	3ph+N+PE	Solid (TN-S)
Solar farm in-feed LV supply	800	3ph+PE	Un-earthed
Low voltage distribution	400/230	3ph+N+PE/ 1ph+N+PE	Solid (TN-S)
AC UPS	400 (In) 400 (Out)	3ph+PE 3ph+N+PE	Solid (TN-S)
DC UPS	400 (In) 110 (Out)	3ph+PE 2+PE	Un-earthed

Table 4 – System voltage levels and Earthing arrangements

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6 UPS & BATTERIES

6.1 EQUIPMENT LIST

The sizing calculations are carried out for the following list of equipment:

1. UP-200F3 - AC UPS - PAS
2. UP-200F4 - AC UPS – Fire & Gas
3. UP-200F1 - DC UPS
4. Batteries for the AC UPS & DC UPS (The battery sizing calculation was carried out considering the use of Sealed NiCd batteries.)

6.2 DESIGN CRITERIA

Each AC UPS system shall have a minimum overload capability of 125% of the rated output current for 10 minutes and 150% of rated output current for 1 minute.

The inverter section of the UPS shall deliver the specified short circuit current.

The design value for inverter short circuit shall be 200% of rated current for 0.1 second, if no value is specified. Battery sizing is independent of the output overload capability of the UPS.

Each AC UPS shall be a redundant system that has two 50% rated batteries (each unit's battery shall be rated for the full rated load and half the autonomy time). The battery type shall be Sealed NiCd or Sealed Gel Filled VRLA (installed on rack).

A UPS system is only considered to be robust where the overall availability is greater than 99.95%. The overall Mean Time Between Failures (MTBF) shall exceed 200,000 hours with a Mean Time to Repair (MTTR) of eight (8) hours. (These exclude outage time for battery discharge testing and assume that spare parts are available at site).

Battery voltage and capacity shall fulfil the inverter's input power requirements when delivering the rated kVA output (whilst also maintaining the output voltage and frequency within permissible tolerances for the entire autonomy time).

The DC UPS will be located within the 66kV / 6.6kV Equipment room (B-100) on the lower deck and have two 100% rated rectifiers connected to a common (shared) battery.

Each UPS shall be a redundant system with a battery sized to support the rated load of each unit for the following autonomy times:

AC UPS – PAS (CCS / SIS / DCS / Field Instruments)	: 30 minutes
AC UPS – FIRE & GAS	: 8 hours
DC UPS	: 60 minutes

6.3 LEGEND

Symbol	Description
Ah	Ampere-Hours
ECV	End of Cell Voltage
I_C	Continuous Load Current
I_{CC}	Delivered Current by UPS
I_i	Momentary Current consumption
I_n	Rated Current of Circuit Breaker
I_{RATED}	Rated Output Current of UPS
K_t	Capacity Rating Factor of Batteries
K_{t1}	Discharge time of Battery at Time t_1
K_{t2}	Discharge time of Battery at Time t_2
N_1	Total Number of Switchgear Feeders
N_2	Number of Circuit Breaker Motor Feeders
N_3	Number of Fuse Contactors
P_C	Total Continuous Load
P_{CU}	Unit Consumption for each Switchgear
P_D	Power Loads Demand
P_E	Engineering contingency (10%)
P_i	Peak Momentary Load
P_N	Maximum Power Demand $P_E + P_T$
P_T	Total power demand (P_D Sum)
S_N	Capacity Rating of UPS
S_S	Spare Capacity of UPS
T_t	Temperature Derating Factor
t, t_1, t_2	Discharge time of Battery
Vdc	Battery Voltage

Table 5 - LEGEND

6.4 EQUATIONS USED FOR UPS SIZING CALCULATIONS

I_{CC} = 2 x I_{RATED}

I_{RATED} = UPS Capacity / (√3 x Output Voltage) for 3-phase UPS output

I_{RATED} = UPS Capacity / (Output Voltage) for 1-phase UPS output

P_N = P_E + P_T

S_S = S_N - P_T

Load current = Load capacity / Minimum Battery voltage

$P_{C\ FINAL}$ = 1.25 * P_C

$P_{I\ FINAL}$ = 1.25 * P_I

I_C = $P_{C\ FINAL}$ / Vdc

I_I = $P_{I\ FINAL}$ / Vdc

6.5 EQUATIONS USED FOR BATTERY SIZING CALCULATIONS

Maximum Battery Voltage = Nominal Battery Voltage + 10%

Minimum Battery Voltage = Nominal Battery Voltage - 10%

Number of Cells = Minimum Battery Voltage / End of Cell Voltage

Calculated Battery capacity = Maximum section size x Temperature correction factor x Aging factor x Design margin

$$\text{Capacity factor, } K_t = \frac{\text{Rated capacity in ampere hours}}{\text{Discharge amperes}}$$

$$\text{Capacity factor, } K_t = K_{t2} - \frac{(K_{t2} - K_{t1}) \times (t_2 - t)}{(t_2 - t_1)}$$

Initial cell capacity (Ah) = Load current (amp) x Time duration (minutes) / 60

6.6 AC UPS - PAS (UP-200F3)

The main purpose of the AC UPS – PAS is to provide secure power supply to SIS controller & I/O cabinet, PCS controller & I/O cabinet, EMCS controller & I/O cabinet, Server cabinet ITER, UCP of vendor packages and UCP of HVAC in electrical & instrument rooms.

The autonomy time of AC UPS – PAS is defined in Doc.no.K559-2254-EL-PHI-002 – 'Electrical System Description & Design Philosophy', as listed below:

- PAS (CCS / SIS / DCS / Field instruments / UCP package) = 30 minutes

6.6.1 Power Supply System

The AC UPS – PAS shall be fed by 400V, 3phase, 50Hz Power supply, neutral solidly earthed by internal transformer, TN-S type.

AC UPS static units and distribution boards will provide the 400V Three phase, 50Hz supply to loads.

The AC UPS – PAS will be fed by LV Switchgear with 3 feeders, namely Line-A, Line-B and bypass supply. The Line-A feeder is essential supply, Line-B and bypass feeders are normal supply. Line-A and Line-B feeders are continuous duty while the bypass feeder is spare duty.

The AC UPS – PAS shall ensure continuity of electric power to the connected load within the specified tolerances without interruption upon failure or deterioration of the normal AC power supply source for a maximum protection time determined by the capacity of the backup batteries installed.

The UPS will provide a reliable, regulated, transient free AC power under normal and abnormal conditions, for the critical loads.

6.6.2 Sizing Requirements

The rated output of the AC UPS – PAS shall be greater than the load requirement.

Battery voltage and capacity shall fulfil the inverter's input power requirements when delivering the rated kVA output (whilst also maintaining the output voltage and frequency within permissible tolerances for the entire autonomy time).

The nominal ampere-hour (Ah) capacity of the battery supplied with the UPS shall include all the necessary allowances required to compensate for aging effects that result in the progressive loss of capacity.

The due temperature design margin to be considered is defined by the Manufacturer taking into account of the minimum temperature foreseen for the installation environment.

The number and size of the outgoing feeders from UPS supply shall be designed such as the correct selectivity among feeders is guaranteed in case of faults and on the basis of the limitation of short circuit current delivered by the UPS during a fault. In case of short circuit on one outgoing feeder, the delivered current (I_{CC}) by UPS can be taken limited to 200% of rated current (I_{RATED}) for 0.1 second.

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If the outgoing circuit breaker (CB) is selected with characteristic of type "B", it clears the fault within approximately 15ms (magnetic operating region) when the fault current is higher than 5 times the rated CB current (I_n); For CB type "C", 10 times the rated CB current shall be considered.

Hence, the condition to be satisfied for the correct choice of outgoing feeder is:

$I_{CC} > 5 \times I_n$ (for "B' type CB)

$I_{CC} > 10 \times I_n$ (for "C' type CB)

where,

$I_{CC} = 2 \times I_{RATED}$

I_{RATED} = UPS Capacity / (√3 x Output Voltage) for 3-phase UPS output

I_{RATED} = UPS Capacity / (Output Voltage) for 1-phase UPS output

The operating characteristic of the CB's shall be type "B" or type "C", according to IEC 60947-2 or other equivalent standards.

The UPS rectifier shall be rated to fulfil the inverter input requirements when the inverter is delivering its rated output and simultaneously recharge the battery within the time specified.

UPS system shall have its neutral solidly earthed by internal transformer.

6.6.3 Power Consumptions

From the Electrical Load List CCS mode 'Import' in Doc.no.123A90-DDL-EL-LIS-20016, total loads powered by AC UPS – PAS are:

Description	Load Demand (kW)		
	P_T	P_E	P_N
Total loads powered by AC UPS - PAS	12.90	2.58	15.48

Table 6 - Power Consumption of AC UPS - PAS

where,

P_T = Total power demand;

P_E = Engineering contingency allowance factor 20% (Contingency 5% + Planned Growth 15%);

$P_N = P_E + P_T$

S_N = Rating of UPS in kVA

6.6.4 UPS Sizing Calculation

Capacity of AC UPS – PAS including Engineering contingency (20%):

P_T = 12.90 kW

P_E = 2.58 kW

P_N = 15.48 kW @ 0.8 power factor = 15.48 / 0.8 = 19.35 kVA

The Selected AC UPS – PAS rating is, S_N = 35 kVA

S_N = 35 kVA (28 kW @ 0.8 power factor)

The final spare capacity of UPS $S_S = S_N - P_T$

S_S = 28 kW – 12.90 kW =15.10 kW @ 0.8 power factor = 18.87 kVA (53.91%)

The selected capacity for 400V, 3-phase, 50Hz AC UPS – PAS system is 35 kVA, redundant system that has two 50% rated batteries (each unit's battery shall be rated for the full rated load and half the autonomy time). The AC UPS – PAS will feed its connected loads at 230V AC Single phase 50Hz 1-phase+N power supply.

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6.6.5 Battery Sizing Calculation

6.6.5.1 Duty Cycle of AC UPS - PAS

The following load profile has been considered.

a.	Battery type	: Sealed Nickel Cadmium (NiCd)	
b.	Output voltage	: 400 V 3-phase TP+N / 230 V Single phase AC, 1P+N	
c.	Nominal DC Bus Voltage	: 216 V	
d.	Maximum battery voltage	: 237.6 Volts	(216V + 10%)
e.	Minimum battery voltage	: 194.4 Volts	(216V – 10%)
f.	Nominal cell voltage	: 1.2 Volts	(as per manufacturer catalogue)
g.	Recommended charging volts	: 1.45 Volts	(as per manufacturer catalogue)
h.	End of cell voltage (ECV)	: 1.00 V	(as per manufacturer catalogue)
i.	Number of cells	: 195	(194.4V / 1.00V = 194.4 cells)

The AC UPS – PAS to have redundant system that has two 50% rated batteries. (each unit's battery shall be rated for the full rated load and half the autonomy time).

The continuous loads capacity	: 12.90 kW
The rated capacity of UPS	: 30.24 kW (UPS capacity 35 kVA x Power factor 0.8 / Efficiency 0.926)
UPS capacity at 0.8 power factor	: 35 kVA
Load current	: UPS capacity / Min. Battery voltage
	: 35 x1000 / 194.4 = 180.04 Amp.
Autonomy duration	: Half the autonomy time of 30 minutes = 15min.

Duty Cycle Duration

Sl	Period	UPS Capacity (kVA)	Min. battery Voltage (Volts)	Load Current (Amp)	Time duration (minutes)	Initial Cell Capacity (Ah)
1	A1	35	194.4	180.04	15	45.01

Table 7 - Duty cycle duration of AC UPS -PAS

Initial cell capacity (Ah) = Load current (amp) x Time duration (minutes) / 60
= 180.04 x 15 / 60 = 45.01 Ah

From battery manufacturer's catalogue, the K_t factor is calculated for the standard cell Ah capacity nearer to the calculated initial cell capacity, as per Equation C.1 in Annex C of IEEE 1115. Refer ANNEXUS for battery manufacturer catalogue.

$$\text{Capacity factor, } K_t = \frac{\text{Rated capacity in ampere hours}}{\text{Discharge amperes}}$$

From battery manufacturer catalogue, for the cell capacity of 48 Ah (type: UP1 M 48)

Rated capacity in ampere hours = 48 Ah

Discharge amperes for 15 min duration = 77.6

K_t = 48 / 77.6 = **0.618**

Temperature derating factor, T_t is considered from Figure A.2 of IEEE 1115.

The Duty Cycle is represented graphically here below:



Figure 4 - Duty cycle graph of AC UPS - PAS

Battery Sizing calculation as per IEEE-1115 for Nickel-Cadmium (NiCd) batteries

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8) = (3) x (6) x (7)	
Period	Load (Amp)	Change in Load (A)	Duration of period (min)	Time to end of section (min)	Capacity rating factor at t min rate (Kt)	Temperature derating factor for t min (Tt)	Required section size (Ah)	
							Positive value	Negative value
Section 1 – First period only								
1	A1=180.04	A1-0= 180.04	M1=15	T=M1=15	0.618	1.00	111.26	0.00
						Section 1 Total	111.26	

Table 8 - Battery sizing calculation AC UPS - PAS

Maximum Section size of battery capacity : 111.26 Ah

Temperature correction factor for 25° C : 1.0

Aging factor : 1.05 (as per IEEE 1106, Annex.E, Figure E.1)

Design Margin : 1.0 (The continuous load capacity is 12.90kW; Battery sizing calculation considers full capacity of UPS 35kVA, hence design margin is not applied.)

Calculated Battery capacity = Maximum section size x Temperature correction factor x Aging factor x Design margin

= 111.26 x 1.0 x 1.05 x 1.0 = 116.82 AH

Selected Battery Capacity : 125 AH x 2 sets.

Two sets of batteries, each with 125 AH is required for the AC UPS – PAS to supply full rated load and half the autonomy time.

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6.7 AC UPS – FIRE & GAS (UP-200F4)

The main purpose of the AC UPS – Fire & Gas is to provide secure power supply to Fire & Gas panel, and System server / Network cabinets.

The autonomy time of AC UPS – FIRE & GAS is defined in Section 3.3 of Doc.no.K559-2254-EL-PHI-002 – 'Electrical System Description & Design Philosophy', as listed below:

- AC UPS – Fire & Gas = 8 hours (i.e. 480 minutes)
  (to include public address, platform audible alarms and status lights)

6.7.1 Power Consumptions

From the Electrical Load List CCS mode 'Import' in Doc.no.123A90-DDL-EL-LIS-20016, total loads powered by AC UPS – FIRE & GAS are:

8 hours Autonomy Loads

Description	Load Demand (kW)		
	P_T	P_E	P_N
Total loads powered by AC UPS – FIRE & GAS	2.70	0.40	3.10

Table 9 - Power consumption of AC UPS - Fire & Gas

where,

P_T = Total power demand;

P_E = Engineering contingency allowance factor 15% (Contingency 0% + Planned Growth 15%);

$P_N = P_E + P_T$

S_N = Rating of UPS in kVA

6.7.2 UPS Sizing Calculation

Capacity of AC UPS –FIRE & GAS including Engineering contingency (10%):

P_T = 2.70 kW

P_E = 0.40 kW

P_N = 3.10 kW @ 0.80 power factor = 3.10 / 0.80 = 3.88 kVA

The Selected AC UPS – PAS rating is, S_N = 15 kVA

S_N = 15 kVA (12.0 kW @ 0.80 power factor)

The final spare capacity of UPS $S_S = S_N - P_T$

S_S = 12.0 kW – 2.70 kW =9.30 kW @ 0.80 power factor = 11.63 kVA (77.53%)

The selected capacity for 400V, 3-phase, 50Hz AC UPS – FIRE & GAS system is 15 kVA, redundant system that has two 50% rated batteries (each unit's battery shall be rated for the full rated load and half the autonomy time). The AC UPS – Fire & Gas will feed its connected loads at 230V AC Single phase 50Hz 1-phase+N power supply.

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6.7.3 Battery Sizing Calculation

6.7.3.1 Duty Cycle of AC UPS – FIRE & GAS

The following load profile has been considered.

j.	Battery type	: Sealed Nickel Cadmium (NiCd)	
k.	Output voltage	: 400 V 3-phase TP+N / 230 V Single phase AC, 1P+N	
l.	Nominal DC Bus Voltage	: 216 V	
m.	Maximum battery voltage	: 237.6 Volts	(216V + 10%)
n.	Minimum battery voltage	: 194.4 Volts	(216V – 10%)
o.	Nominal cell voltage	: 1.2 Volts	(as per manufacturer catalogue)
p.	Recommended charging volts	: 1.45 Volts	(as per manufacturer catalogue)
q.	End of cell voltage (ECV)	: 1.00 V	(as per manufacturer catalogue)
r.	Number of cells	: 195	(194.4V / 1.00V = 194.4 cells)

The AC UPS –Fire & Gas to have redundant system that has two 50% rated batteries. (each unit's battery shall be rated for the full rated load and half the autonomy time).

The continuous loads capacity	: 2.70 kW
The rated capacity of UPS	: 12.96 kW (UPS capacity 15 kVA x Power factor 0.8 / Efficiency 0.926)
UPS capacity at 0.8 power factor	: 15 kVA
Load current	: UPS capacity / Min. Battery voltage
	: 15 x 1000 / 194.4 = 77.16 Amp.
Autonomy duration	: Half the autonomy time of 480 minutes = 240min.

Duty Cycle Duration

Sl	Period	UPS Capacity (kVA)	Min. battery Voltage (Volts)	Load Current (Amp)	Time duration (minutes)	Initial Cell Capacity (Ah)
1	A1	15	194.4	77.16	240	308.64

Table 10 - Duty cycle duration of of AC UPS - Fire & Gas

Initial cell capacity (Ah) = Load current (amp) x Time duration (minutes) / 60
= 77.16 x 240 / 60 = 308.64 Ah

For 4 hours (240 min) battery manufacturer catalogue does not provide discharge amperes.

Where time t falls between two times (t1 and t2) for which data are available, the Kt factor for time t is calculated by interpolation using the formula shown in Equation (A.1) of IEEE 1115.

$$\text{Capacity factor, } K_t = K_{t2} - \frac{(K_{t2} - K_{t1}) \times (t_2 - t)}{(t_2 - t_1)}$$

Capacity factor, Kt is calculated for 240 minutes (4 hours) as detailed below:

From battery manufacturer catalogue, for the cell capacity of 320 Ah (type: UP1 M 320)

Discharge time t (min)	Time t_1 from data (min)	Time t_2 from Data (min)	(1) Ampere for time t_1 (A)	(2) Ampere for time t_2 (A)	Factor K_{t1} for Time t_1 320 / (1)	Factor K_{t2} for Time t_2 320 / (2)	Factor K_t for Time t
240	180	300	103	64	3.106	5.00	4.053

Table 11 - Capacity factor Kt of of AC UPS - Fire & Gas

Rated capacity in ampere hours (Ah) = 320 Ah (type: UP1 M 320)

Capacity factor required for duration, t = 240 minutes

Time t_1 = 180 minutes (3 hours)

Time t_2 = 300 minutes (5 hours)

Discharge amperes for Time t_1 = 103 A

Discharge amperes for Time t_2 = 64 A

Capacity Factor K_{t1} for Time t_1 = Ah Capacity / Discharge amperes for Time t_1

= 320 / 103 = 3.106

Capacity Factor K_{t2} for Time t_2 = Ah Capacity / Discharge amperes for Time t_2

= 320 / 64 = 5.00

$$\text{Capacity factor, } K_t = K_{t2} - \frac{(K_{t2} - K_{t1}) \times (t_2 - t)}{(t_2 - t_1)}$$

$$\text{Capacity factor, } K_t = 5.00 - \frac{(5.00 - 3.106) \times (300 - 240)}{(300 - 180)}$$

K_t = **4.053** (for 240 minutes duration, i.e. 4 hours)

Temperature derating factor, Tt is considered from Figure A.2 of IEEE 1115.

The Duty Cycle is represented graphically here below:

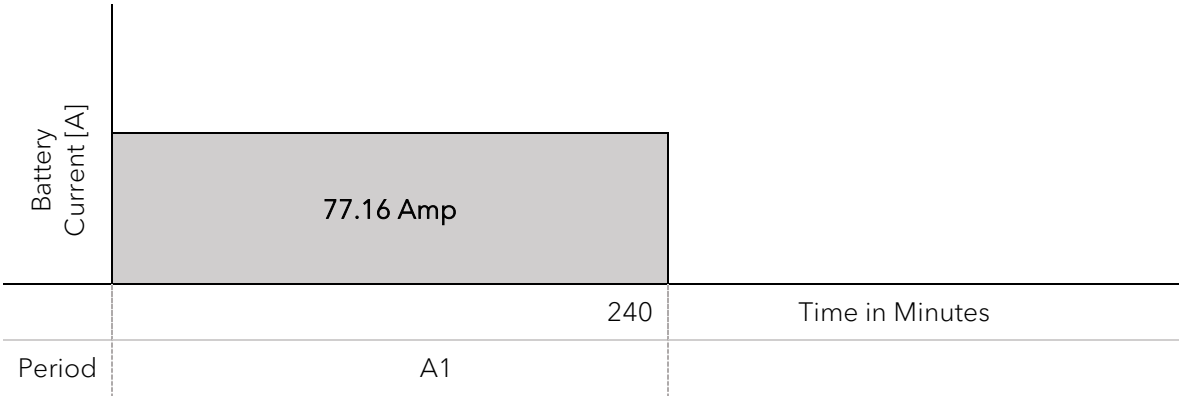


Figure 5 - Duty cycle graph of of AC UPS - Fire & Gas

Battery Sizing calculation as per IEEE-1115 for Nickel-Cadmium (NiCd) batteries

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8) = (3) x (6) x (7)	
Period	Load (Amp)	Change in Load (A)	Duration of period (min)	Time to end of section (min)	Capacity rating factor at t min rate (Kt)	Temperature derating factor for t min (Tt)	Required section size (Ah)	
							Positive value	Negative value
Section 1 – First period only								
1	A1=77.16	A1-0= 77.16	M1=240	T=M1=240	4.053	1.00	312.73	0.00
						Section 1 Total	312.73	

Maximum Section size of battery capacity : 312.73 Ah

Temperature correction factor for 25° C : 1.0

Aging factor : 1.05 (as per IEEE 1106, Annex.E, Figure E.1)

Design Margin : 1.0 (The continuous load capacity is 2.70kW; Battery sizing calculation considers full capacity of UPS 15kVA, hence design margin is not applied.)

Calculated Battery capacity = Maximum section size x Temperature correction factor x Aging factor x Design margin

= 312.73 x 1.0 x 1.05 x 1.0 = **328.37 AH**

Selected Battery Capacity : 345 AH x 2 sets

Two sets of batteries, each with **345 AH** is required for the AC UPS – Fire & Gas to supply full rated load and half the autonomy time.

6.8 DC UPS (UP-200F1)

The main purpose of the DC UPS is to provide control power supply to 66kV and 6.6kV switchgears auxiliary. The energy storage capability is defined as minimum 60 minutes in case of source supply failure.

6.8.1 System Supply

The DC UPS systems shall be fed by 400V, 3phase, 50Hz Power supply, neutral solidly earthed by internal transformer, TN-S type.

DC UPS static units and distribution boards will supply the 110V DC.

The DC UPS will be located within the 66kV and 6.6kV Equipment room (B-100) on the lower deck and have two 100% rated rectifiers connected to a common (shared) battery.

6.8.2 Power Consumptions

From the Electrical Load List CCS mode 'Import' in Doc.no.123A90-DDL-EL-LIS-20016, total loads fed by DC UPS are:

60 minutes Autonomy Loads

Description	Load Demand (kW)		
	P_T	P_E	P_N
Total loads powered by DC UPS	2.60	0.52	3.12

Table 12 - Power consumption of DC Battery System

where,

P_T = Total power demand;

P_E = Engineering contingency allowance factor 20% (Contingency 5% + Planned Growth 15%);

$P_N = P_E + P_T$

S_N = Rating of UPS in kVA

6.8.3 UPS Sizing Calculation

Capacity of DC UPS – Switchgears control including Engineering contingency (10%):

P_T = 2.60 kW

P_E = 0.52 kW

P_N = 3.12 kW @ 1.0 power factor = 3.12 / 1.0 = 3.12 kVA

The Selected DC UPS rating is, S_N = 10 kVA

S_N = 10 kVA (10 kW @ 1.0 power factor)

The final spare capacity of UPS $S_S = S_N - P_T$

S_S = 10.0 kW – 2.60 kW = 7.4 kW @ 1.0 power factor = 7.4 kVA (74%)

The selected capacity for DC UPS – Switchgears control is 10 kVA, redundant system that has two 100% rated rectifiers connected to a common (shared) battery.

The DC UPS – Switchgears control will have input supply of 400V, 3phase, 50Hz AC, TP and it will provide 110V DC output control power supply to the 66kV & 6.6kV switchgears.

6.8.4 110V DC Battery Sizing Calculation

The following inputs have been considered for the 110V DC Battery sizing calculation:

a.	Battery type	: Sealed Nickel-Cadmium (NiCd)	
b.	Output voltage	: 110Vdc	
c.	Maximum battery voltage	: 121 Volts	(110V + 10%)
d.	Minimum battery voltage	: 99 Volts	(110V – 10%)
e.	Nominal cell voltage	: 1.2 Volts	(as per manufacturer catalogue)
f.	Recommended charging volts	: 1.45 Volts	(as per manufacturer catalogue)
g.	End of cell voltage (ECV)	: 1.00 Volts	(as per manufacturer catalogue)
h.	Number of cells	: 99	(99V / 1.00V = 99 cells)

The DC UPS System to have redundant system that has two 100% rated rectifiers and one common (shared) battery.

The continuous loads capacity	: 2.60 kW
The rated capacity of UPS	: 11.63 kW (UPS capacity 10 kVA x Power factor 1.0 / Efficiency 0.86)
UPS capacity at 1.0 power factor	: 10 kVA
Load current	: UPS capacity / Min. Battery voltage
	: 10 x 1000 / 99 = 101.01Amp.
Autonomy duration	: 60 min.

Duty Cycle Duration

Sl	Period	UPS Capacity (kVA)	Min. battery Voltage (Volts)	Load Current (Amp)	Time duration (minutes)	Initial Cell Capacity (Ah)
1	A1	10	99	101.01	60	101.01

Table 13 - Duty cycle duration of DC Battery System

Initial cell capacity (Ah) = Load current (amp) x Time duration (minutes) / 60
= 101.01 x 60 / 60 = 101.01 Ah

From battery manufacturer's catalogue, the Kt factor is calculated for the standard cell Ah capacity nearer to the calculated initial cell capacity, as per Equation C.1 in Annex C of IEEE 1115. Refer ANNEXUS for battery manufacturer catalogue.

$$\text{Capacity factor, } K_t = \frac{\text{Rated capacity in ampere hours}}{\text{Discharge amperes}}$$

From battery manufacturer catalogue, for the cell capacity of 125 Ah (type: UP1 M 125)

Rated capacity in ampere hours = 125 Ah

Discharge amperes for 60 min duration = 105

K_t = 125 / 105 = **1.19**

Temperature derating factor, T_t is considered from Figure A.2 of IEEE 1115.

The Duty Cycle is represented graphically here below:

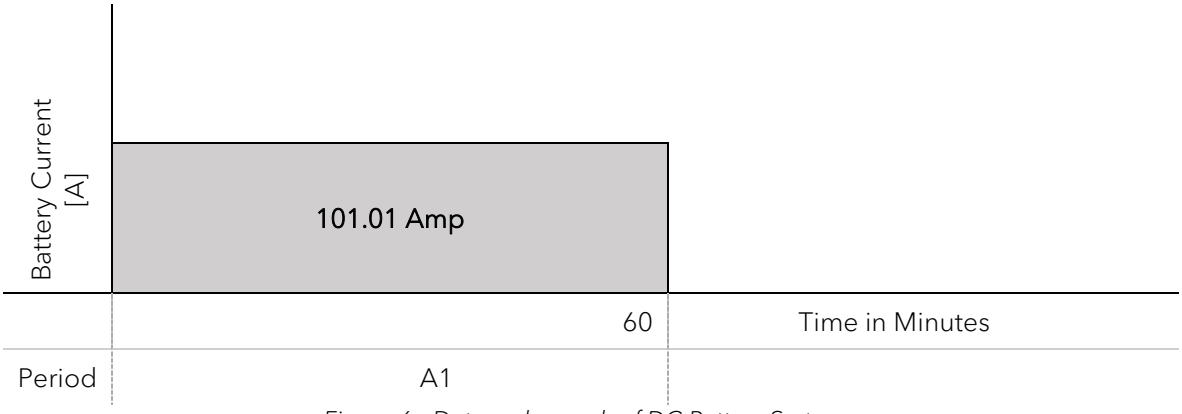


Figure 6 - Duty cycle graph of DC Battery System

Battery Sizing calculation as per IEEE-1115 for Nickel-Cadmium (NiCd) batteries

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8) = (3) x (6) x (7)	
Period	Load (Amp)	Change in Load (A)	Duration of period (min)	Time to end of section (min)	Capacity rating factor at t min rate (Kt)	Temperature derating factor for t min (Tt)	Required section size (Ah)	
							Positive value	Negative value
Section 1 – First period only								
1	A1=101.01	A1-0= 101.01	M1=60	T=M1=60	1.19	1.00	120.20	0.00
						Section 1 Total	120.20	

Table 14 - Battery sizing calculation DC Battery System

Maximum Section size of battery capacity : 120.20 Ah

Temperature correction factor for 25° C : 1.0

Aging factor : 1.05 (as per IEEE 1106, Annex.E, Figure E.1)

Design Margin : 1.0 0 (The continuous load capacity is 1.60kW; Battery sizing calculation considers full capacity of UPS 10kVA, hence design margin is not applied.)

Calculated Battery capacity = Maximum section size x Temperature correction factor x Aging factor x Design margin

= 120.20 x 1.0 x 1.05 x 1.0 = **126.21 AH**

Selected Battery Capacity : 125 AH x 1 set.

One set of batteries with **125 AH** is required for the DC UPS to supply full rated load for the autonomy time.

6.9 RESULTS SUMMARY

The results of the UPS & Batteries sizing calculation are summarized as below:

Sl.	Description	No. of cells / set	Capacity	Configuration	Autonomy duration	Power supply
AC UPS – PAS (CCS / SIS / DCS / FIELD INSTRUMENTS) (UP-200F3)						
1	AC UPS - PAS	-	35 kVA	Redundant system that has two 100% rated rectifiers & inverters with common bypass & common output.	30 minutes. (each set battery with 15 minutes autonomy at full load)	3 IN: 400V 3ph, AC, 50Hz OUT: 400V 3ph+N and 230V 1ph+N AC, 50Hz
2	Batteries	195 cells 1.2 V Ni-Cd	125 AH x 2 sets	2 sets of batteries each rated for full load and 50% autonomy		
AC UPS – FIRE & GAS (UP-200F4)						
3	AC UPS - FIRE & GAS	-	15 kVA	Redundant system that has two 100% rated rectifiers & inverters with common bypass & common output.	8 hours. (each set battery with 4 hours autonomy at full load)	3 IN: 400V 3ph, AC, 50Hz OUT: 400V 3ph+N and 230V 1ph+N AC, 50Hz
4	Batteries	195 cells 1.2 V Ni-Cd	345 AH x 2 sets	2 sets of batteries each rated for full load and 50% autonomy		
DC UPS – SWITCHGEARS CONTROL (UP-200F1)						
5	DC Battery system – Switchgears control	-	10 kVA	Redundant system that has two 100% rated rectifiers	60 minutes autonomy at full load	2 IN: 400V 3ph, AC, 50Hz OUT: 110V DC
6	Batteries	99 cells 1.2 V Ni-Cd	125 AH x 1 set	One common (shared) battery.		

Table 15 - Results summary

7 ANNEXES

7.1 REFERENCES FROM IEEE-1115 STANDARD

a) Calculation of Capacity rating factor, K_t of batteries

To calculate a K_t factor from discharge data for prolonged float charging, the rated capacity of the cell is divided by the discharge current for the specified time and end-of-discharge voltage, as shown in Equation (C.1):

$$K_t = \frac{\text{Rated capacity in ampere hours}}{\text{Discharge current in amperes}} \qquad \text{(C.1)}$$

Figure 7 - Capacity rating factor Kt

Where time t falls between two times (t_1 and t_2) for which data are available, the K_t factor for time t is calculated in the following table by interpolation using the formula shown in Equation (A.1):

$$K_t = K_{t_2} - \frac{\left(K_{t_2} - K_{t_1}\right)\times\left(t_2 - t\right)}{\left(t_2 - t_1\right)} \qquad \text{(A.1)}$$

Note that interpolation should be performed only on the K_t factors. Interpolation of current values will yield incorrect results.

Table A.3—Calculation of capacity rating factors (K_t) for KM438P Cell Type

Discharge Time t (min)	Time t_1 From Data (min)	Time t_2 From Data (min)	(1) Amperes for Time t_1 (A)	(2) Amperes for Time t_2 (A)	Factor Kt_1 for Time t_1 438 ÷ (1)	Factor Kt_2 for Time t_2 438 ÷ (2)	Factor Kt for Time t
0.083	0.017	1	1041	743	0.421	0.590	0.432
0.583	0.017	1	1041	743	0.421	0.590	0.518
30	30		315		1.390		1.390
59.92	30	60	315	246	1.390	1.780	1.779
60	60		246		1.780		1.780
90	90		198		2.212		2.212
119.92	90	120	198	164	2.212	2.671	2.670
120	120		164		2.671		2.671
150	120	180	164	127	2.671	3.449	3.060
179.92	120	180	164	127	2.671	3.449	3.448
180	180		127		3.449		3.449

Figure 8 - Calculation of capacity rating factor Kt

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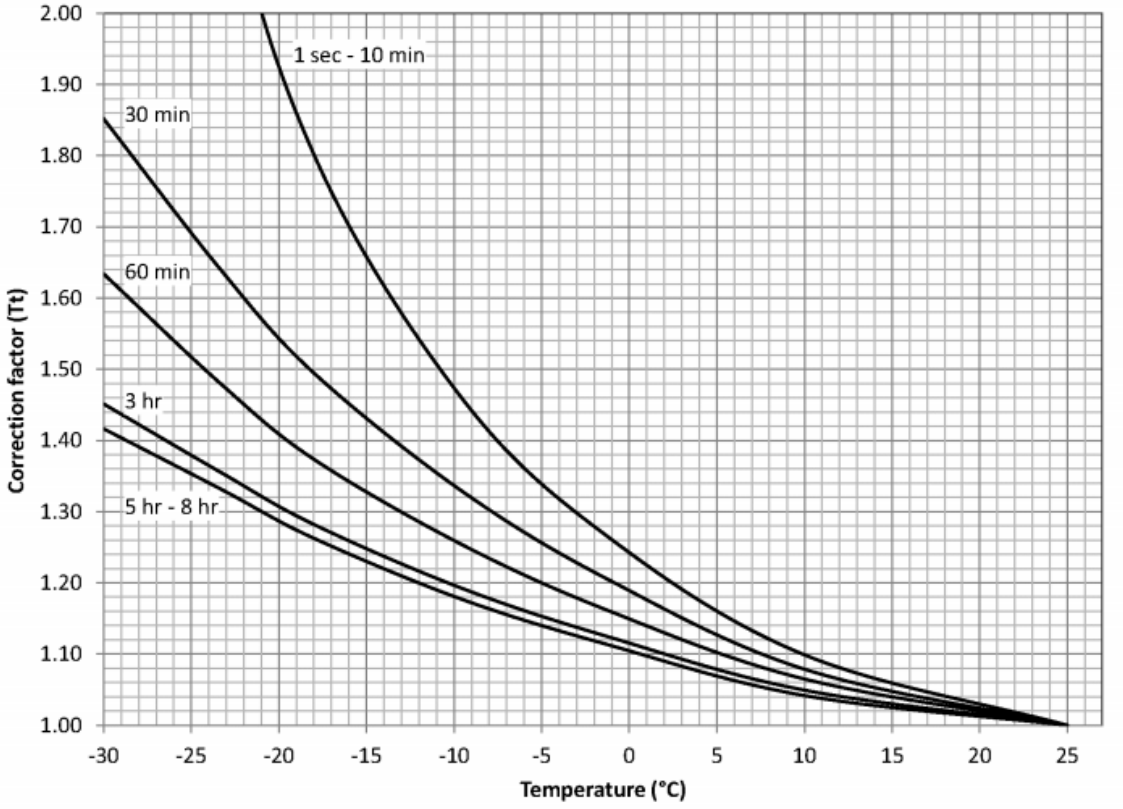


Figure A.2—Hypothetical temperature derating curves for KM cell manufactured by ABC Company

Figure 9 - Temperature de-rating curve

7.2 BATTERY MANUFACTURER CATALOGUE PAGES

Nickel-Cadmium Battery catalogue of "SAFT Industrial Battery Group - France"

Electrical performance – M Range

Performance after prolonged float charge of fully charged cells

Available amperes at +20°C ± 5°C (+68°F ± 9°F) → Final voltage: 1.00 V/cell

L type	C_5	Hours							Minutes							Seconds		
	Ah	10	8	5	3	2	1.5	1	45	30	20	15	10	5	1	30	5	1
UP1 M 8	8	0.82	1.02	1.60	2.60	3.72	4.66	6.61	7.91	9.79	11.6	12.9	14.3	16.9	17.4	19.1	23.7	27.5
UP1 M 16	16	1.65	2.04	3.20	5.20	7.44	9.32	13.2	15.8	19.6	23.1	25.9	28.7	33.7	34.8	38.2	47.5	55.1
UP1 M 24	24	2.47	3.06	4.80	7.80	11.2	14.0	19.8	23.7	29.4	34.7	38.8	43.0	50.6	52.2	57.3	71.2	82.6
UP1 M 32	32	3.30	4.08	6.40	10.4	14.9	18.6	26.4	31.6	39.1	46.2	51.7	57.4	67.5	69.6	76.5	95.0	110
UP1 M 40	40	4.12	5.10	8.00	13.0	18.6	23.3	33.1	39.6	48.9	57.8	64.7	71.7	84.4	87.0	95.6	119	138
UP1 M 48	48	4.94	6.12	9.6	15.6	22.3	28.0	39.7	47.5	58.7	69.4	77.6	86.1	101	104	115	142	165
UP1 M 65	65	6.70	8.29	13.0	21.1	30.2	37.9	53.7	64.3	79.5	93.9	105	117	137	141	155	193	224
UP1 M 75	75	7.73	9.56	15.0	24.3	34.5	43.2	62.7	74.6	91.1	104	111	118	135	137	147	174	191
UP1 M 100	100	10.3	12.8	20.0	32.3	46.0	57.6	83.6	99.5	121	138	148	157	180	182	196	231	255
UP1 M 125	125	12.9	15.9	25.0	40.4	57.5	72.0	105	124	152	173	185	196	225	228	245	289	318
UP1 M 150	150	15.5	19.1	30.0	48.5	69.0	86.4	125	149	182	207	222	235	270	274	294	347	382
UP1 M 170	170	17.5	21.7	34.0	55.0	78.2	97.9	142	169	206	235	251	267	306	310	334	393	433
UP1 M 195	195	20.1	24.9	39.0	63.1	89.7	112	163	194	237	269	288	306	351	356	383	451	497
UP1 M 220	220	22.7	28.1	44.0	71.1	101	127	184	219	267	304	325	345	396	401	432	509	560
UP1 M 245	245	25.2	31.2	49.0	79.2	113	141	205	244	298	338	362	384	441	447	481	567	624
UP1 M 270	270	27.8	34.4	54.0	87.3	124	156	226	269	328	373	399	424	486	493	530	625	688
UP1 M 295	295	30.4	37.6	59.0	95.4	136	170	247	294	358	407	436	463	530	538	579	682	751
UP1 M 320	320	33.0	40.8	64.0	103	147	184	268	318	389	442	473	502	575	584	628	740	815
UP1 M 345	345	35.5	44.0	69.0	112	159	199	288	343	419	476	510	541	620	629	677	798	879
UP1 M 370	370	38.1	47.2	74.0	120	170	213	309	368	449	511	547	580	665	675	726	856	943
UP1 M 395	395	40.7	50.4	79.0	128	182	228	330	393	480	545	584	620	710	721	775	914	1006
UP1 M 420	420	43.3	53.6	84.0	136	193	242	351	418	510	580	621	659	755	766	824	972	1070
UP1 M 445	445	45.8	56.7	89.0	144	205	256	372	443	540	614	658	698	800	812	873	1029	1134
UP1 M 490	490	50.5	62.5	98.0	158	225	282	410	488	595	676	725	769	881	894	961	1134	1248
UP1 M 540	540	55.6	68.9	108	175	248	311	451	537	656	745	799	847	971	985	1060	1249	1376
UP1 M 590	590	60.8	75.2	118	191	271	340	493	587	716	814	873	926	1061	1076	1158	1365	1503
UP1 M 640	640	65.9	81.6	128	207	294	369	535	637	777	883	947	1004	1151	1168	1256	1481	1630
UP1 M 690	690	71.1	88.0	138	223	317	397	577	687	838	952	1021	1082	1241	1259	1354	1596	1758
UP1 M 740	740	76.2	94.4	148	239	340	426	619	736	899	1021	1095	1161	1331	1350	1452	1712	1885
UP1 M 785	785	80.9	100	157	254	361	452	656	781	953	1084	1161	1231	1412	1432	1540	1816	2000
UP1 M 835	835	86.0	106	167	270	384	481	698	831	1014	1153	1235	1310	1501	1523	1638	1932	2127
UP1 M 885	885	91.2	113	177	286	407	510	740	881	1075	1222	1309	1388	1591	1615	1737	2047	2254
UP1 M 935	935	96.3	119	187	302	430	539	782	930	1135	1291	1383	1467	1681	1706	1835	2163	2382
UP1 M 985	985	101	126	197	318	453	567	823	980	1196	1360	1457	1545	1771	1797	1933	2279	2509
UP1 M 1030	1030	106	131	206	333	474	593	861	1025	1251	1422	1524	1616	1852	1879	2021	2383	2624
UP1 M 1130	1130	116	144	226	365	520	651	945	1124	1372	1560	1671	1773	2032	2062	2217	2614	2879
UP1 M 1230	1230	127	157	246	398	566	708	1028	1224	1494	1698	1819	1930	2212	2244	2414	2845	3133
UP1 M 1330	1330	137	170	266	430	612	766	1112	1323	1615	1836	1967	2086	2392	2427	2610	3077	3388

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Figure 10 - Battery manufacturer catalogue – SAFT Industrial Group - France