Handbook for Stationary Vented Lead-Acid Batteries

Part 2: Installation, Commissioning and Operation

Contents

1. Transport, Delivery and Stock Receipt

1.1 Land-Carriage of Vented and VRLA Batteries

Cells / blocks must be transported in an upright position.

Batteries without any visible damage are not defined as dangerous goods under the regulations for transport of dangerous goods by road (ADR) or by railway (RID).

The must be protected against short circuits, slipping, falling down or damaging. Cells / blocks may be stacked on pallets on a suitable way and if secured (ADR and RID, special provision 598). It is prohibited to staple pallets.

No dangerous traces of acid shall be found on the exteriors of the packaging unit.

Cells / blocks whose containers leak or are damaged must be packed and transported as class 8 dangerous goods under UN no. 2794.

1.2 Sea Transport of Vented Batteries

Vented cells / blocks, filled with acid, must be packed and transported as dangerous goods acc. to IMDG.

Classification:

UN-no.:	2794
Class:	8

The transport in wooden crates or on pallets is permitted if the following additional regulations are observed:

- Cells / blocks must be transported in upright position, must not show signs of damages, must be protected against short circuits, slipping, falling down or damaging.
- It is prohibited to staple cells.
- Blocks can be stapled secured by isolating intermediate layers if the poles are not loaded by the above lying units.
- It is prohibited to staple pallets.

- Electrolyte must not escape from the cell / the block being in a declination of 45 degree.

1.3 Sea Transport of VRLA Batteries

The following exemplary mentioned lines of products*) are not classified as dangerous goods acc. to IMDG because they fulfill also the IATA-clause A 67:

Sonnenschein GF-Y, GF-V, A200, A400, A500, A600, A600 SOLAR, A700, PowerCycle, dryfit military, SOLAR and SOLAR BLOCK
Absolyte
Element (former: Champion)
Marathon
Sprinter
Powerfit
drysafe
AGM military

*) Certificates on request

1.4 Air Transport of Unfilled Vented Lead-Acid Batteries

There are no restrictions for the transport.

1.5 Air Transport of Filled Vented Lead-Acid Batteries

Filled and charged vented batteries are dangerous goods with regard to air transport and can be jet by freight planes only. Hereby, the IATA packaging regulation 800 must be observed.

In case of air transport, batteries which are part of any equipment must be disconnected at their terminals, and the terminals must be protected against short-circuits. This is in order to avoid the risk of any incidents like fire etc.

1.6 Air Transport of VRLA Batteries

The following exemplary mentioned lines of products*) are not classified as dangerous goods acc. to the IATA-clause A 67:

Sonnenschein GF-Y, GF-V, A200, A400, A500, A600, A600 SOLAR, A700, PowerCycle, dryfit military, SOLAR and SOLAR BLOCK
Absolyte
Element (former: Champion)
Marathon
Sprinter
Powerfit
drysafe
AGM military

*) Certificates on request

In case of air transport, batteries which are part of any equipment must be disconnected at their terminals, and the terminals must be protected against short-circuits. This is in order to avoid the risk of any incidents like fire etc.

1.7 Abbreviations

ADR: The European Agreement Concerning the International Carriage of Dangerous Goods by Road (covering most of Europe).
RID: Regulations concerning the International Carriage of Dangerous Goods by Rail (covering most of Europe, parts of North Africa and the Middle East).
IMDG: The International Maritime Dangerous Goods Code.
IATA: The International Air Transportation Association (worldwide).
ICAO: Civil Aviation Organization’s Technical Instructions for the Safe Transport of Dangerous Goods by Air.

1.8 Delivery and Stock Receipt

- GNB Industrial Power’s vented batteries are delivered from our factories, logistic centers or via our distributors.

- The delivery items can be identified either by the number and type of cells / blocks or by referring to a battery drawing.

- Check the package or pallet for integrity.

- Do not stack one pallet above the other.

- Heed handling instructions stated on the packages.

- During transportation take all precaution to avoid breaking those products which are considered to be „fragile“ and have been identified as such.

- GNB Industrial Power chooses for all products a package suitable for the kind of dispatch. If any damage is observed during unloading the goods, the carrier should be notified within 48 hours.

- Parcels are insured up to the delivery address acc. to the order, if this is agreed by the sales contract.

2. Safety

For any operation on the batteries, from storage to recycling, the following safety rules should be observed:

- Read commissioning instructions and report”, installation Instructions and operating instructions thoroughly.

- No smoking. No naked flame!

- Always wear protective rubber gloves, glasses and clothing (incl. safety shoes).

- Even when disconnected, a battery remains charged. The metallic parts of a battery are electrically active.

- Always use isolated tools.

- Never place tools on the batteries (in particular, metallic parts can be dangerous).

- Check torques in case of unsecured screw connections of inter-cell and inter-block connectors.

- Never pull up or lift cells / blocks at the terminals.

- Avoid impacts or abrupt loads.

- Never use synthetic clothes or sponges to clean the cells / blocks, but water only (wet clothes) without additives [1].

- Avoid electrostatic charges and discharges/sparks.

3. Storage

In the users interest the storage time should be as short as possible. Cells/block batteries are not fully charged anymore on delivery.

3.1 Preconditions and Preparations

Remove and avoid, respectively, contaminations on surfaces, dust etc..

The storage location should fulfill the following preconditions:

- Protect the cells / blocks from harsh weather, moisture and flooding.

- Protect the cells / blocks from direct or indirect sun radiation

- The storage area and ambient, respectively, must be clean, dry, frost-free (see also chapter 3.2) and well looked after.

- Cells / blocks must be protected from short-circuits by metallic parts or conductive contaminations.

- Cells / blocks must be protected from dropping objects, from falling down and falling over.

3.2 Storage Conditions

- The temperature has an impact on the self-discharge rate of filled and charged cells and blocks (see fig. 1 and 2).
- Storage on a pallet wrapped in plastic material is permitted, in principle. However, it is not recommended in rooms where the temperature fluctuates significantly, or if high relative humidity can cause condensation under the plastic cover. With time, this condensation can cause a whitish hydration on the poles and lead to high self-discharge by leakage current.
  As an exception filled and fully charged lead-acid batteries can be stored also at temperatures below zero if dry surface of cells or blocks is guaranteed and if condensation or dew effects or similar cannot occur.
- Stacking of pallets is not permitted.
- Avoid storing of unpacked cells / blocks on sharp-edged supports.
- It is recommended to realize the same storage conditions within a batch, pallet or room.

3.3 Storage Time

3.3.1 Filled and Charged Cells / Blocks

The maximum storage time at a temperature of 20 °C is 3 months. After that refreshing charging is necessary. The intervals for refreshing charging are kept short in order to avoid or to minimize so-called “shedding” (which can occur especially at the poles and straps) and possible consequences (short circuits).

Higher temperatures cause higher self-discharge and shorter storage time between re-charging operations (see fig. 1 and 2), e.g. at 30 °C: re-freshening charge after 1.5 months.

OGi-cells have a slightly higher self-discharge rate because the also slightly higher antimony content even if within the < 3 %-criterion.

3.3.2 Unfilled and Charged (Dry, Pre-charged) Cells / Blocks

The storage time of dry, pre-charged cells / blocks is unlimited theoretically. The positive electrodes are protected by their PbO_2-layer, the negative electrodes by an extra conservation. But the protection and the conservation, respectively, can go down due to climatic influences (changing humidity, strong temperature fluctuations) (see commissioning instructions in appendix 2). Therefore, a maximum storage time of 2 years is recommended. In case of doubtful storage conditions suitable counteractions shall be realized, e.g. shrink wrapping of cells/blocks in protective foils together with desiccant.

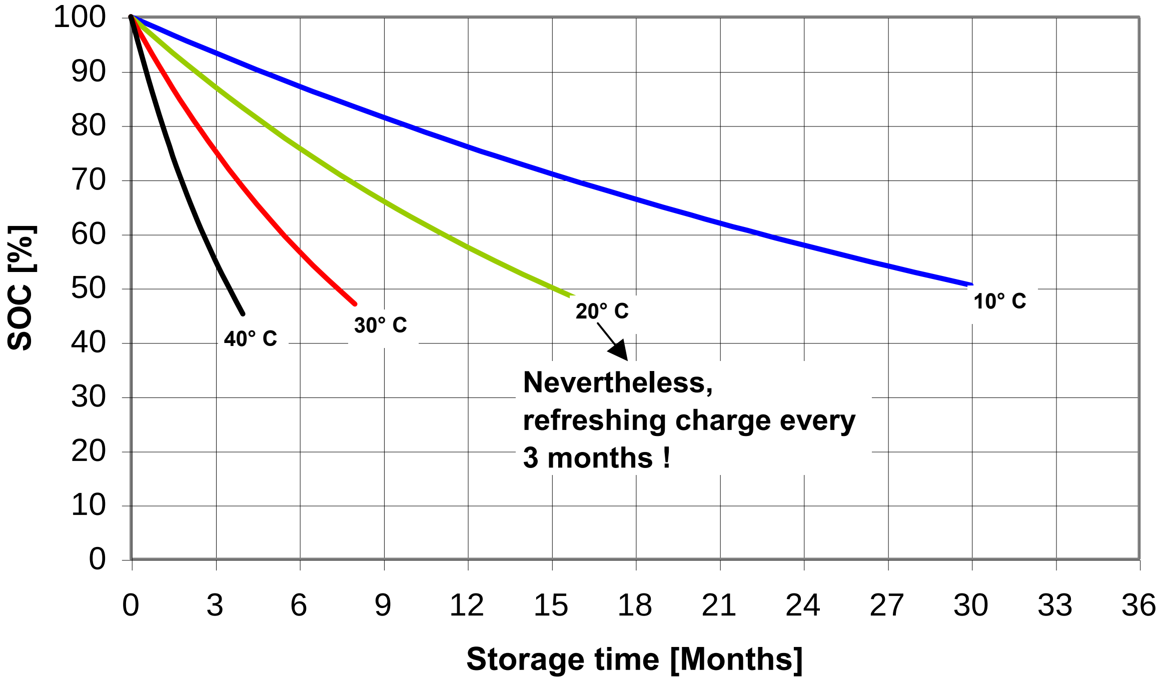


Fig. 1: OGi, OPzS, OCSM, Energy Bloc - State of Charge (SOC) respectively available Capacity vs. Storage Time at different Temperature

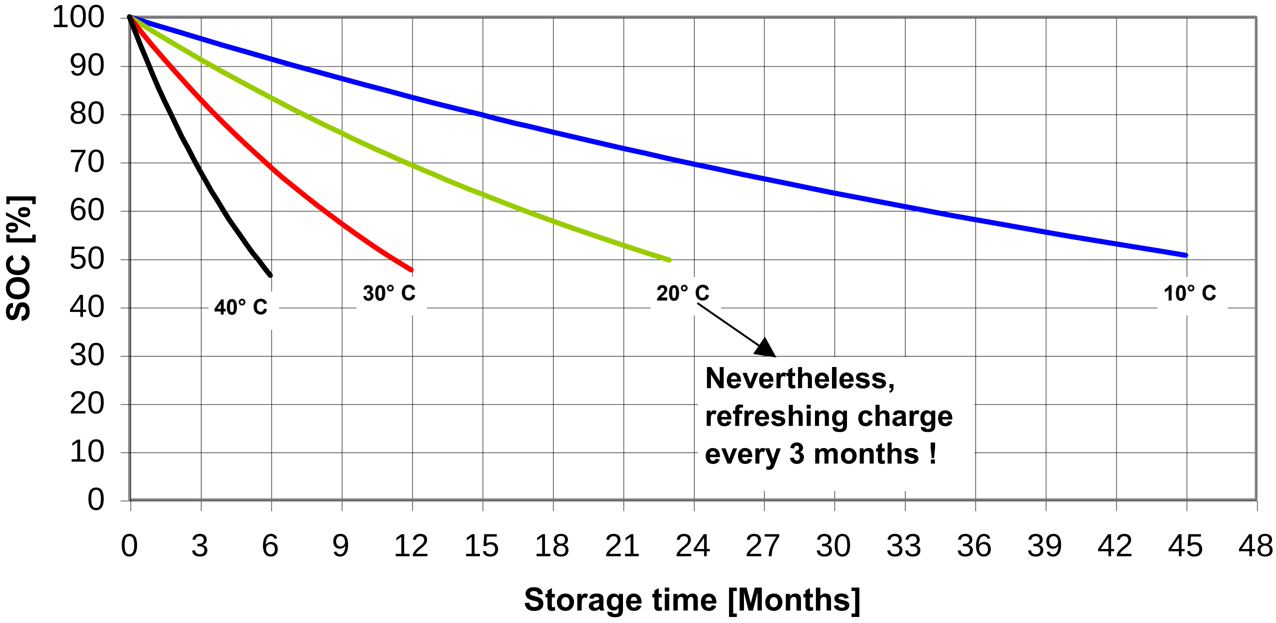


Fig. 2: GroE - State of Charge (SOC) respectively available Capacity vs. Storage Time at different Temperatures

3.4 Measures during Storage or Taking out of Operation

- Appropriate inventory turnover based on a FIFO-method ("First In – First Out") avoids over-storage.
- The following measures go also for filled and charged cells / blocks taken out of operation temporary.
- If cells / blocks must be cleaned, never use solvents, but water (wet clothes) without additives [1].
- Refreshing charging (intervals in acc. with item 3.3.1): IU-charging (constant current / constant voltage-charging) at temperatures between 15 and 35 °C:

Max. voltage [Vpc]	Min. voltage [Vpc]	Current [A]	Charging time [h] at max. voltage
2.40	2.23	unlimited	72

Table 1: Charge voltages and charge time

- Depending on the charger the charging time shall be extended by 24 hours for every 0.04 V less than the maximum voltage, in which 2.23 Vpc is still the minimum voltage.

- Alternatively to regular refreshing charges, float charge operation acc. to chapter 6.1 can be applied in case of temporary taking out of operation.

4. Assembly and Installation

4.1 Battery Rooms, Ventilation and General Requirements

General: This is a guideline only and consists of excerpts from national and international standards and guidelines. See EN 50272-2 [2] respectively equivalent IEC 62485-2 [14] for detailed information. Also, follow up commissioning instructions/report, installation instructions and operating instructions.

4.1.1 Temperature

The battery room temperature should be between + 10 °C and + 30 °C. Optimal temperature is the nominal temperature 20 °C. The maximum temperature difference between cells or blocks, respectively, within a string must not exceed 5 degree C (5 Kelvin).

4.1.2 Room Dimensions and Floor Composition

Battery rooms' height shall be at least 2 m above the operating floors. Floors shall be reasonable level and able to support the battery weight.
The floor surface must be electrolyte resistant for usage of vented batteries.

Notice:
Electrolyte resistant floor surface is not necessary in case of vented batteries, if they are placed in trays. Those trays must hold at least the amount of electrolyte of one cell or block.

From EN 50272-2 [2]: "…The floor area for a person standing within arm's reach of the battery (see note 2) shall be electrostatic dissipative in order to prevent electrostatic charge generation. The resistance to a groundable point measured according to IEC 61340-4-1 shall be less than 10 MΩ.

Conversely the floor must offer sufficient resistance R for personnel safety. Therefore the resistance of the floor to a groundable point when measured in accordance with IEC 61340-4-1 shall be

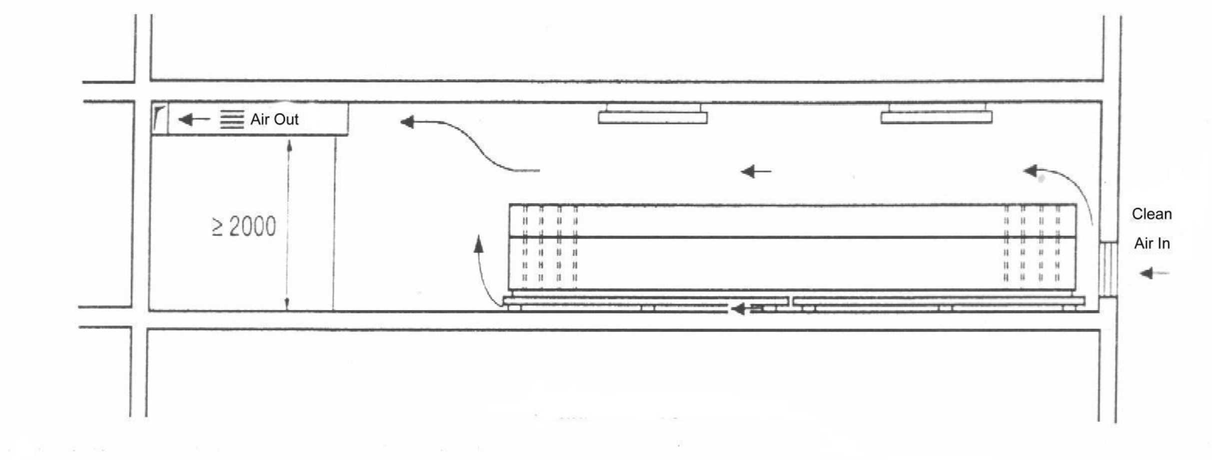
for battery nominal voltage ≤ 500 V: 50 kΩ ≤ R ≤ 10 MΩ
for battery nominal voltage > 500 V: 100 kΩ ≤ R ≤ 10 MΩ

Note 1:
To make the first part of the requirement effective, the personnel shall wear anti-static footwear when carrying out maintenance work on the battery. The footwear shall comply with EN 345.

Note 2:
Arm's reach: 1.25 m distance (For definition of arm's reach see HD 384.4.41.)…"

Room inlets and outlets: The way of air circulation should be as shown below.

A minimum distance between inlet and outlet of 2 m is requested acc. to EN 50272-2 [2], if inlet and outlet are located on the same wall.



4.1.3 Ventilation

Battery rooms must be vented acc. to EN 50272-2 [2] in order to dilute gas (hydrogen and oxygen) evolved with charging and discharging and to avoid explosions. Therefore, “EX”-protected electrical installation is not necessary. It must be designed for wet room conditions.

Do not install batteries in airtight enclosures.

Spark generating parts must have a safety distance to cell or block openings (respectively valves) as specified in EN 50272-2 [2].

Heaters with naked flame or glowing parts or devices are forbidden. Heater’s temperature must not exceed 300 °C.

Hand lamps are only allowed with switches and protective glass according to protection class II and protection class IP 54.

4.1.3.1 Ventilation Requirements

From EN 50272-2 [2]: „ …The minimum air flow rate for ventilation of a battery location or compartment shall be calculated by the following formula…:

$$Q = 0.05 \cdot n \cdot I_{gas} \cdot C_{rt} \cdot 10^{-3} \, [m^3/h]$$

With n = number of cells

I_{gas} = $I_{float\ or\ boost}$ [mA/Ah] relevant for calculation (see table 2)

C_{rt} = capacity C_{10} for lead acid cells (Ah), U_f = 1.80 V/cell at 20 °C...”

The following table states the values for I_{gas} to be used:

Operation	Vented cells (Sb < 3%)	VRLA cells
Float charging	5	1
Boost charging	20	8

Table 2: I_{gas} acc. to EN 50272-2 [2] for IU- and U-charging depending on operation and lead acid battery type (up to 40 °C operating

temperature). The gas producing current I_{gas} can be reduced to 50 % of the values for vented cells in case of use of recombination vent plugs (catalyst).

With natural ventilation (air convection) the minimum inlet and outlet area is calculated as follows:

$$A \geq 28 \cdot Q \; [cm^2]$$

(Air convection speed ≥ 0.1 m/s)

Example 1:

Given: 220 V battery, 110 cells, C_{10} = 400 Ah, vented type, Antimony (Sb) < 3 % (LA) in float service.

Calculation of fresh air necessary:

$$Q = 0.05 \cdot n \cdot I_{gas} \cdot C_{rt} \cdot 10^{-3} \; [m^3/h]$$

With $n = 110$
$I_{gas} = 5$ (see table 2)
$C_{rt} = 400$

$Q = 11 \; m^3/h$ $A \geq 308 \; cm^2$

Example 2:

Same battery as in example 1, but VRLA-type.

$I_{gas} = 1$ to be used (instead of 5).

$Q = 2.2 \; m^3/h$ $A \geq 62 \; cm^2$

Note:
A calculation program is available on request.

4.1.3.2 Close Vicinity to the Battery

From EN 50272-2 [2]: „…In the close vicinity of the battery the dilution of explosive gases is not always secured. Therefore a safety distance extending through air must be observed within which sparking or glowing devices (max. surface temperature 300 °C) are prohibited. The dispersion of explosive gas depends on the gas release rate and the ventilation close to the source of release. For calculation of the safety distance d from the source of release the following formula applies assuming a hemispherical dispersal of gas...

Note:
The required safety distance d can be achieved by the use of a partition wall between battery and sparking device.

Where batteries form an integral part of a power supply system, e.g. in a UPS system the safety distance d may be reduced according to the equipment manufacturers safety calculations or measurements. The level of air ventilation rate must ensure that a risk of explosion does not exist by keeping the hydrogen content in air below $1\%_{\mathbf{vol}}$ plus a safety margin at the potential ignition source…“.

Taking into account the number of cells results in the following formula for the safety distance d:

$$d = 28.8 \cdot \left(\sqrt[3]{N} \right) \cdot \sqrt[3]{I_{gas}} \cdot \sqrt[3]{C_{rt}} \quad [mm] \;{}^{*})$$

*) "…Depending on the source of gas release the number of cells per block battery (N) or vent openings per cell involved (1/N) must be taken into consideration, i. e. by the factor $\sqrt[3]{N}$, respectively $\sqrt[3]{1/N}$ ..."

Example 1:

Cell, vented type, one vent, 100 Ah.
Float charge → I_{gas} = 5 (acc. to table 2).

Safety distance d = 28.8 • 1 • 1.71 • 4.64 = 228.5 mm → 230 mm

Example 2:

12 V-block, six cells, one opening in the top cover, vented type, 100 Ah.

Float charge → I_{gas} = 5 (acc. to table 2).

$\sqrt[3]{N}$ = 1.82, because six cells

Safety distance d = 28.8 • 1.82 • 1.71 • 4.64 = 415.8 mm → 420 mm

Example 3:

Cell, VRLA-type, one vent, 100 Ah.
Float charge → I_{gas} = 1 (acc. to table 2).

Safety distance d = 28.8 • 1 • 1 • 4.64 = 133.6 mm → 135 mm

Example 4:

Cell, vented type, one vent, 1500 Ah.
Boost charge → I_{gas} = 20 (acc. to table 2)

Safety distance d = 28.8 • 1 • 2.71 • 11.45 = 893.6 mm → 895 mm

Example 5:

Cell, vented type, three vents, 3000 Ah.
Boost charge → I_{gas} = 20 (acc. to table 2)

$\sqrt[3]{1/N}$ = 0.69 because three vents per cell

Safety distance d = 28.8 • 0.69 • 2.71 • 14.42 = 776.6 mm → 780 mm

4.1.4 Electrical Requirements (Protection, Insulation, Resistance etc.)

To prevent a build-up of static electricity when handling batteries, material of clothing, safety boots and gloves are required to have a surface resistance of $\leq 10^8\,\Omega$, and an insulation resistance of $\geq 10^5\,\Omega$.

From EN 50272-2 [2]: “…The minimum insulation resistance between the battery’s circuit and other local conductive parts should be more than 100 Ω per Volt (of battery nominal voltage) corresponding to a leakage current < 10 mA…

Note:
The battery system should be isolated from the fixed installation before this test is carried out. Before carrying out any test check for hazardous voltage between the battery and the associated rack or enclosure….”

In case of battery systems with > DC 120 V nominal voltage battery racks or cabinets made from metal shall either be connected to the protective conductor (grounding) or insulated from the battery and the place of installation (chapter 5.2 in EN 50272-2 [2]). This insulation must withstand 4000 V AC for one minute.

Note:
Protection against both direct and indirect contact shall only be used for battery installations with nominal voltages up to DC 120 V. In these cases the requirements for metal battery stands and cabinets specified in chapter 5.2 of EN 50272-2 [2] do not apply.

Touch protection must be provided for all active parts at voltages > 60 V DC with insulation, covers or shrouds and distance.

4.1.5 Installation (Racks, Cabinets)

Batteries shall be installed in clean, dry locations. Batteries must be secured against dropping objects and protected from dust.

The course width between battery rows is equal to 1.5 times the cell depth (replacement) but minimum 600 mm (acc. to EN 50272-2 [2]).

The minimum distance for > 120 V between active parts is 1.5 m or insulation, insulated cover etc.

The recommended minimum distance between cells or blocks (of VRLA type) is 10 mm. At least 5 mm are requested acc. to EN 50272-2 [2] (at the largest dimension). Thus, in order to allow heat dissipation.

Racks and cabinets shall have a distance of at least 100 mm to the wall for a better placement of connections and better access for cleaning.

Batteries must allow service with normal insulated tools (acc. to EN 50272-2 [2]).

Batteries with a nominal voltage ≥ 75 V requires an EC-declaration of conformity from the installer of the battery in accordance with the low-voltage directive 2006/95/EC (replaces 73/23/EEC). The declaration of conformity confirms that the installation of the battery was carried out in acc. with the applicable standards and that the CE-symbol was fixed at the battery. The installer of the battery system is responsible for the declaration and fixing the CE-symbol. See [3] for more information.

4.2 Preparations

- Dry, pre-charged cells and blocks must be filled by acid and commissioned first (see chapter 5.2).

- If drawings were supplied by GNB Industrial Power, they must be kept during the assembly.

- The racks or cabinets should provide adequate ventilation above and below to allow the heat produced by the batteries and their charging system to escape. The distance between cells or blocks shall be approx. 10 mm, but at least 5 mm. See appendix 2 and standard EN 50272-2 [2].

- The grounding of racks or cabinets should be carried out in acc. with EN 50272-2 [2].

4.3 Actual Assembly

- Use insulated tools for the assembly. Wear rubber gloves, protective glasses and protective clothing (incl. safety shoes). Remove metallic objects like watches and jewelry (see also chapter 2.).

- The installation must be carried out only with the supplied original accessories, e.g. connectors, or with accessories recommended by GNB Industrial Power. The same goes for spare parts in case of later repairs.

- Pole inserts and contact areas of connectors must be moistened slightly by acid-free pole grease. Don’t use any substances based on paraffin.

- The screw-connections should be tightened by the following torques:

GroE, OCSM, OGi ≥ 260 Ah, OPzS-cells, OPzS Solar-cells	Energy Bloc, OPzS blocks, OPzS Solar-blocks	OGi ≤ 250 Ah	EnerSol T
(20 ±1) Nm	(12 ±1) Nm	(8 ±1) Nm	(25 ±1) Nm

Table 3: Torques

- Check the overall battery voltage. It should comply with the number of cells / blocks connected in series. The open-circuit voltage of the individual cells / blocks should not vary themselves from the measured average value by more than the plus/minus-tolerances listed below (guide values):

2 V-cells:	± 0.02 V
6 V-blocks:	± 0.035 V
12 V-blocks:	± 0.049 V

- If necessary, the transportation plugs to be removed and replaced by the delivered plugs.

4.4 Parallel Arrangements

The most battery manufacturers, standards and guidelines recommend a maximum of 4 strings in parallel. More than 4 parallel strings are quite possible without reducing the life.

Preconditions and features for 2 up to 10 strings in parallel:

- The connector cables for positive and negative terminals of each battery string must have the same length.

- It is a must to have a circuit breaker for each string or, at least, for every two strings.

- The strings must have the same temperature.

Parallel connection of strings with different capacities as well as different age is possible. The current during both, discharge and re-charging, will be split acc. to the capacity or age, respectively. For more information, see [4].

Also different lead-acid battery models or types of different technology (vented, valve-regulated) can be connected in parallel as long as the requested charging voltage (Vpc) per string acc. to the operating instructions is fulfilled.

If these requirements are fulfilled paralleling of up to 10 strings is possible. All battery performance data have to be applied to the end terminal of each string.

Always connect the individual series strings first. Check that the different strings have the same state of charge, means similar open circuit voltages. After that, connect the strings in parallel.

5. Commissioning

5.1 Commissioning of Filled and Charged Cells / Blocks

- For float charge applications, commissioning after a storage period or assembly in accordance with the conditions specified above, commissioning consists merely of connecting the battery to its charging system. This should take place as soon as possible after receipt of the battery. If this is not possible, advises acc. to chapter 3.4 shall be taken into account because cells/block batteries have lost charge already due to transport and temporary storage.

- The charge voltage should be adjusted in accordance with the specifications as described in chapter 6.1.

- The safety systems: Fuses, circuit breakers and insulation monitoring shall be all tested independently.

- If a capacity test is requested, for instance, for an acceptance test on site, make sure the battery is fully charged. For this, the following IU-charge methods can be applied:

  Option 1: Float charge $\geq$ 72 hours.

Option 2: 2.40 Vpc ≥ 16 hours (max. 48 hours) followed by float charge ≥ 8 hours.

- The current available for charging can be unlimited up to achieving the constant voltage level (guide values: 10 A and 35 A per 100Ah nominal capacity).

- Nominal electrolyte densities:
  - GroE: 1.22 kg/l at 20 °C
  - OPzS, OPzS-Block, Energy Bloc, OGi ≤ 250 Ah: 1.24 kg/l at 20 °C
  - OPzS-Solar: 1.24 kg/l at 25 °C
  - OCSM, OGi ≥ 260 Ah: 1.26 kg/l at 20 °C
  - EnerSol T: 1.26 kg/l at 25 °C
  - EnerSol: 1.28 kg/l at 25 °C

  Permissible tolerance during operation: ± 0.01 kg/l

5.2 Commissioning of Unfilled and Charged (Dry, Pre-charged) Cells / Blocks

5.2.1 General Items

- The commissioning is carried out by filling the cells respectively blocks with sulphuric acid in the necessary density.

  Densities of filling acid:
  - GroE: 1.21 kg/l at 20 °C
  - OPzS, OPzS-Block, Energy Bloc, OGi ≤ 250 Ah: 1.23 kg/l at 20 °C
  - OPzS-Solar: 1.23 kg/l at 25 °C
  - OCSM, OGi ≥ 260 Ah: 1.25 kg/l at 20 °C
  - EnerSol T: 1.25 kg/l at 25 °C
  - EnerSol: 1.27 kg/l at 25 °C

  The rest time after filling should be at minimum 2 hours, to ensure that the plate material is completely activated. Depending on the total number of cells on minimum 4 to 8 cells (pilot cells) the temperature and the electrolyte density has to be measured and to be recorded in the commissioning report.

- On non-transparent containers the vent plugs remain open, to being able to observe, if at the end of the charging all cells show an even gassing. It is important that the initial charging is carried out completely, which is possible only, if the charging voltage is > 2.35 Vpc. Interruptions have to be possibly avoided. The commissioning has to be recorded in the commissioning report.

- During the commissioning charge the cell voltage of the pilot cells has to be measured and after completion of the commissioning charge the cell voltage, the electrolyte density and the temperature of all cells has to be measured and recorded in the commissioning report including the time.

- The electrolyte temperature must not exceed 55 °C. If necessary, the charging needs to be interrupted.

5.2.2. Commissioning Charge with Constant Current / Constant Voltage (IU-Charging Regime)

A charging voltage of (2.35 to 2.4) Vpc is necessary. The charging current at the beginning of the charging should be minimum 5 A per 100 Ah C10. The electrolyte density during charging is slowly increasing only. Therefore the charging time, to achieve a minimum electrolyte density, corresponding to a nominal density of minus 0.01 kg/l, can take several days. After the necessary electrolyte density has been achieved a switch over to the float charge voltage in accordance with the operating instructions (see appendix 2) should be carried out. The density of the electrolyte will increase during operation to the nominal value.

5.2.3 Commissioning Charge with Constant Current (I-Charging Regime) or Downdraft Current (W-Charging Regime)

The maximum allowed currents can be taken from following table 4:

Charging regime	Charging current per 100 Ah C_{10}
I-charging regime	5.0 A
W-charging regime	
at: 2.0 Vpc	14 A
2.4 Vpc	7.0 A
2.65 Vpc	3.5 A

Table 4: Charging regimes and charging currents

Charging has to be carried out till all cells have achieved a voltage of minimum 2.6 V, all cells show an increase of electrolyte density to the nominal value of ± 0.01 kg/l and these values do not increase during additional 2 hours. After this a switch over to the float charge voltage in accordance with 6.1 (see also the operating instructions, appendix 2) should be carried out.

5.2.4 Extended Commissioning Charge

- Because of long lasting storage or climatic influences (humidity, temperature fluctuation) the charging condition of the cells will decrease. This makes an extended commissioning charge in accordance with the following process necessary:

  - Charging with 15 A per 100 Ah C_{10} till 2.4 Vpc are achieved (approx. 3 to 5 hours),
  - 14 hours charging with 5 A per 100 Ah C_{10} (voltage exceeds 2.4 Vpc),
  - One hour break,
  - 4 hours charging with 5 A per 100 Ah C_{10}.

- The last two items have to be repeated till all cells have achieved a voltage of minimum 2.6 V, all cells show an increase of electrolyte density to a nominal value of ± 0.01 kg/l and these values do not increase during additional 2 hours. After this a switch over to the float charge voltage in accordance with 6.1 (see also the operating instructions, appendix 2) should be carried out.

- In case of a necessary capacity test, e.g. an acceptance test on site, the battery has to be charged before testing > 8 hours with the float charge voltage.

5.3 Electrolyte and Water for Topping up

5.3.1 Acid for Filling

After dilution with water to values of ≤ 1.30 kg/l, the impurities should in no case exceed the values mentioned in the following table 5.

Cons. no.	Impurities	mg/l max.
1	metal of platinum group	0.05
2	rhenium	0.1
3	copper	0.5
4	other metals of the hydrogen sulfide group beside than lead, e.g. arsenic, antimony, bismuth, tin, selenium, tellurium	
	individually	1.0
	all together	2.0
5	manganese, chromium, titanium, nickel	
	individual	0.2
6	iron	30
7	other metals of the ammonium sulfide group beside than aluminum and zinc, e.g. cobalt	
	individually	1.0
	all together	2.0
8	halogens calculated as chloride	5
9	nitrogen as nitrate	10
10	nitrogen as e.g. ammonia	50
11	volatile organic acids calculated as acetic acid	20
12	oxidable organic substances calculated as $KMnO_4$-consumption	30
13	annealing residue	250

Table 5: Permitted impurities of diluted sulphuric acid as filling acid for lead-acid batteries in the density range of ≤ 1.30 kg/l (acc. to [5])

5.3.2 Operating Electrolyte

For the operating electrolyte the maximum values of the following table 6 are valid.

Cons. no.	Impurities		mg/l2) max.
1	metals of platinum group		n.n1)
2	rhenium		n.n1)
3	copper		n.n1)
4	tellurium and selenium	individually	1.0
5	other metals of the hydrogen sulfide group		
	beside than lead, e.g. arsenic, bismuth,	individually	3.0
		all together	6.0
6	antimony		
	a) Gro-, GroE-, OGi-cells		3
	b) GiS-, PzS-, OPzS-cells		10
7	manganese, chromium, titanium, nickel		
		individually	0.2
8	iron		100
9	other metals of the ammonium sulfide group		
	beside than aluminum and zinc, e.g. cobalt,	individually	1.0
		all together	2.0
10	halogen calculated as chloride		
	a) Gro-, GroE-, OGi-, OPzS-cells		50
	b) GiS-, PzS-cells		500
11	nitrogen as nitrate		10
12	nitrogen as e.g. ammonia		50
13	volatile organic acids as acetic acid		30
14	oxidable organic substances calculated as $KMnO_4$-consumption		50

1) These metals will be separated completely on the negative electrode. The influence of these pollutants will increase the self-discharge.

2) It is impossible to mention generally valid limiting values for metals. The for batteries harmful contents are among others depending on type, age and operating conditions of the cell.

Table 6: Permissible impurities of diluted sulphuric acid as operating electrolyte for lead acid batteries in the density range of ≤ 1.30 kg/l (acc. to [5])

5.3.3 Refill Water

The refill water is cleaned (max. conductivity 30 µS/cm) and the maximum values mentioned in the following table 7 are valid.

Cons. no.	Impurities		mg/l max.
1	evaporation residue		10
2	oxidable organic substances,		
	calculated as $KMnO_4$-consumption		20
3	metals of the hydrogen sulfide group		
	(Pb, Sb, As, Sn, Bi, Cu, Cd)		
	each element	individually	0.1
		all together	0.5
4	metals of the ammonium sulfide group		
	(Fe, Co, Ni, Cu, Cr)		
	each element	individually	0.1
		all together	0.5
5	halogens calculated as chloride		0.5
6	nitrogen as nitrate		2.0
7	nitrogen as e.g. ammonia		40

Table 7: Chemical requirements for cleaned water (acc. to [5]).
The mentioned value are not allowed to be exceeded.

5.3.4 Mixing of Sulphuric Acid

A high heat evolution must be taken into consideration when mixing concentrated sulphuric acid. Therefore hard rubber or heat resistant plastic containers should be used only, no glass containers.

The necessary electrolyte to fill dry-charged cells will be made by mixing of (de-mineralized / completely desalinized) water and sulphuric acid of a density of e.g. 1.71kg/l. Highest caution has to be taken. The sulphuric acid has to be added to the cleaned water in a thin jet only by permanently stirring of the cleaned water. It shall never be handled vice versa, which means pouring water to the sulphuric acid. This causes the risk of explosion!

To achieve the exact amount of electrolyte with the desired density the mentioned values of fig. 3 have to be taken.

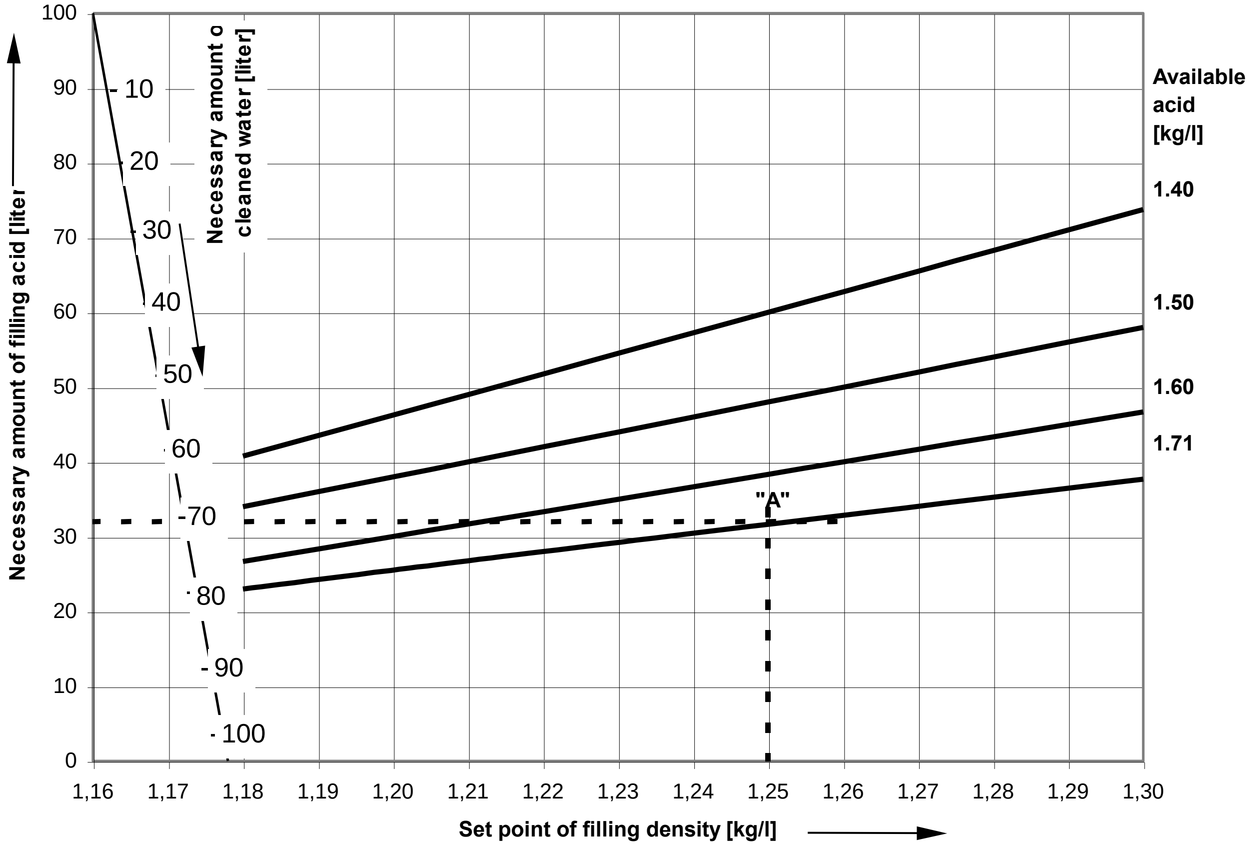


Fig. 3: Amount of Acid and Water versus Set Point of Filling Acid

Example:

40 liters of filling acid with a density of 1.25 kg/l are needed. Available is sulphuric acid with a density of 1.71 kg/l.

In the diagram of Fig. 3 the dot “A“ has to be determined at the intersection point of the vertical axis at 1.25 kg/l “Set point of the filling acid density” and the suitable axis 1.71kg/l “Available acid”.

If now a horizontal line from dot “A“ to y-axis is drawn, the intersection point to 71 liter “Necessary amount of cleaned water “ and 32 liter “Necessary amount of filling acid” shows up.

These amounts 71 liters of cleaned water
+ 32 liters of sulphuric acid with a density of 1.71 kg/l
result, because of contraction, in 100 liter of electrolyte with a density of 1.25 kg/l.

The in diagram Fig 3 mentioned amounts are related to 100 liters and 20°C.

For 40 liters of filling acid the following is needed:

0.4 • 71 liters = 28.4 liters of cleaned water
+ 0.4 • 32 liters = 12.8 liters acid with a density of 1.71 kg/l.

The density is depending on the temperature (fig. 4), and see also chapter 6.10.

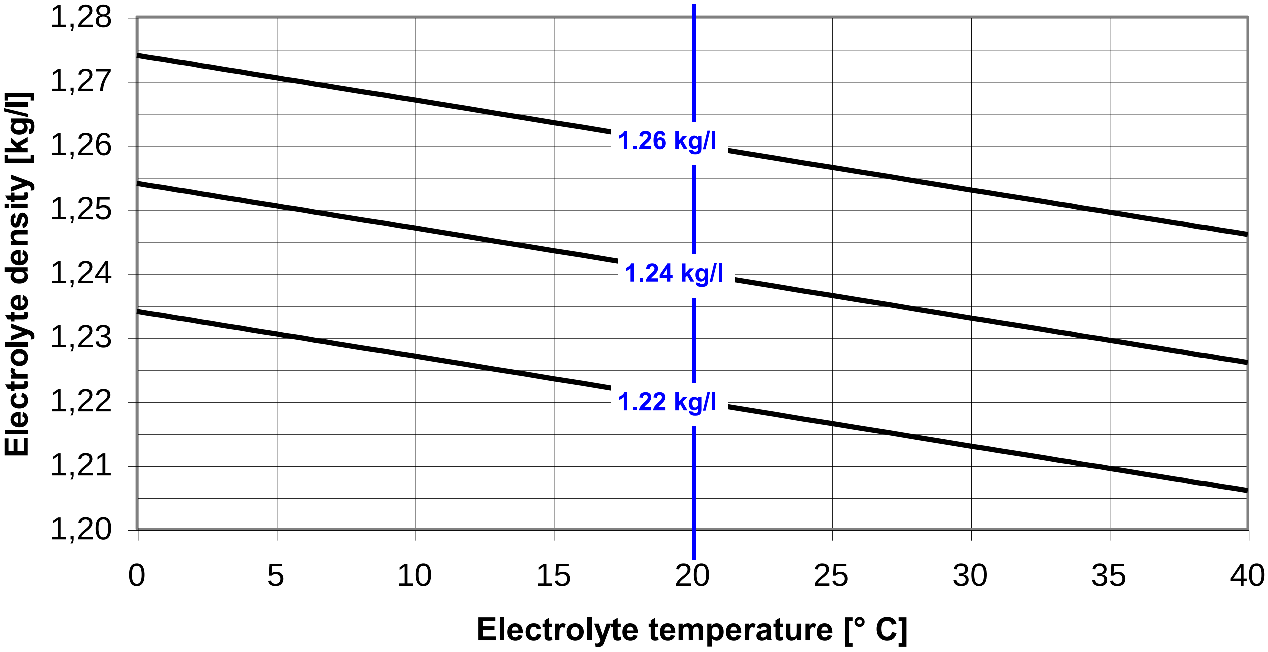


Fig. 4: Electrolyte Density versus Electrolyte Temperature

5.3.5 Adjustment of Operating Electrolyte Density

The operating electrolyte density may need adjustment because e.g. incorrect filling. Here, two cases must be distinguished:

Case A: The measured electrolyte density is too high (at nominal temperature and nominal electrolyte level).

$$x = \frac{(b - a) \bullet 1000}{b - 1}$$

<u>Case B:</u> The measured electrolyte density is too low (at nominal temperature and nominal electrolyte level).

$$y = \frac{(a - b) \bullet 1000}{c - b}$$

wherein

x = amount of electrolyte to be replaced by water in cm^3/l

y = amount of electrolyte to be replaced by acid of higher density in cm^3/l

a = kg/l H_2SO_4 of the required density

b = kg/l H_2SO_4 of the measured density

c = kg/l H_2SO_4 with higher density used for the adjustment

6. Operation

6.1 Float Voltage and Float Current

- A temperature related adjustment of the charge voltage within the operating temperature of 10 °C to 30 °C is not necessary. If the operating temperature is permanently outside this range, the charge voltage has to be adjusted as shown in figures 5 and 6.

  The float charge voltage should be set as follows. Hereby, the Volts per cell multiplied by the number of cells must be measured at the end terminals of the battery:

  2.23 Vpc for OPzS, OPzS-Block, OPzS Solar, OGi, Energy Bloc, GroE;
  2.25 Vpc for OCSM, EnerSol T;
  2.27 Vpc for EnerSol

  All charging (float, boost, equalizing) must be carried out according to an IU-characteristic with limit values: I-phase: ± 2%; U-phase: ± 1%. These limits are acc. to the standard DIN 41773, part 1 [6]. The charge voltage shall be set or corrected, respectively, to the values mentioned above.

- In the case of installation in cabinets or in trays, the representative ambient temperature measurement is achieved at a height of 1/3. The sensor should be placed in the center of this level.

- The location of battery temperature sensors depends on the probes. The measurement shall be carried out either at the negative terminals (pointed metallic probes or probes with loop-shape) or on the plastic housing (flat probes to be placed on top or on one side in the center).

- As a clue about the fully charged state the following rough formula can be used: The battery is fully charged if the residual charge current does not change anymore considerably during three hours. The mixing of electrolyte can take much longer and is finished if the nominal electrolyte density can be measured.

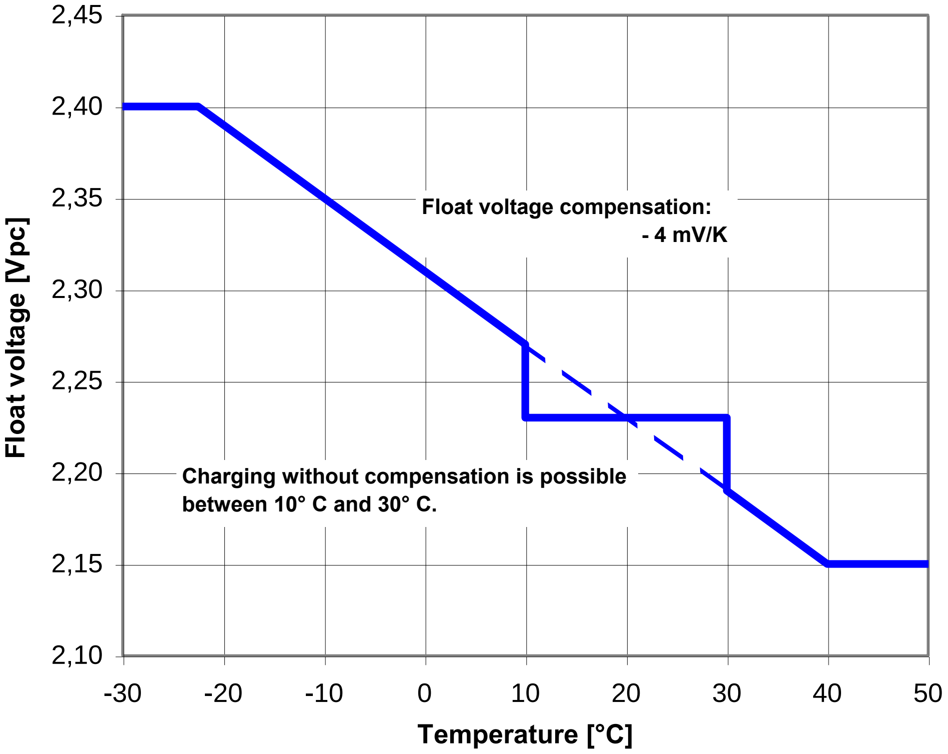


Fig. 5: Float Voltage versus Temperature – OPzS, OPzS-Block, OPzS Solar, OGi, Energy Bloc, GroE

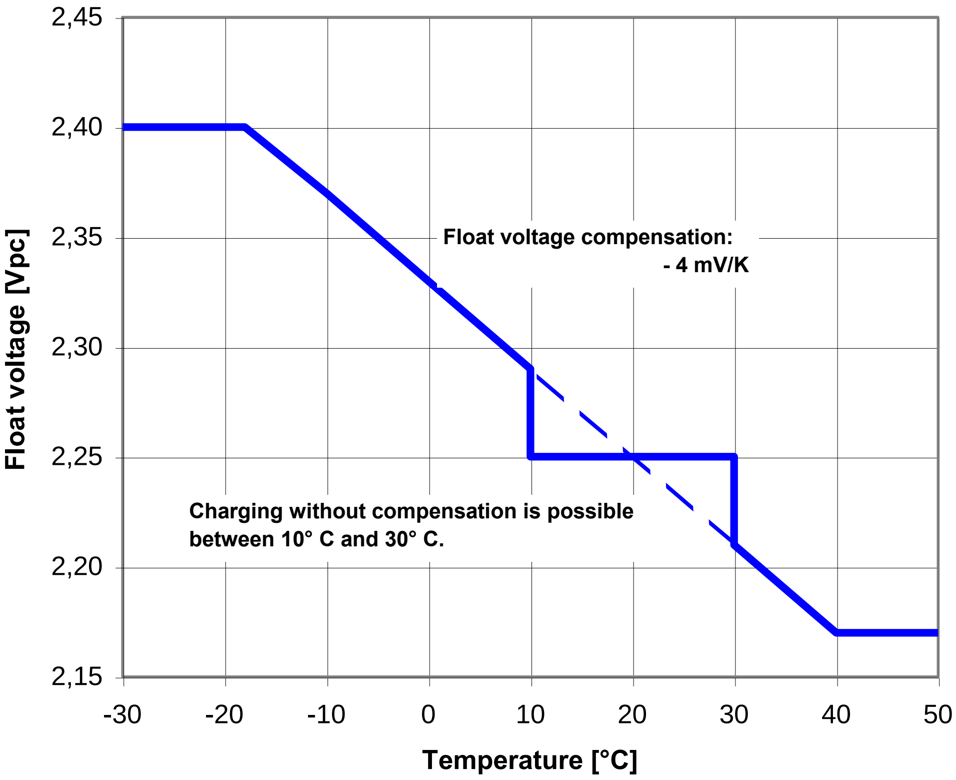


Fig. 6: Float voltage versus Temperature - OCSM, EnerSol T

6.2 Superimposed AC Ripple

Depending on the electrical equipment (e.g. rectifier, inverter), its specification and charging characteristics alternating currents flow through the battery superimposing onto the direct current during charge operation.

Alternating currents and the reaction from the loads may lead to an additional temperature increase of the battery and “shallow cycling” (i.e. cycling with low depths of discharges), which can shorten the battery life.

Possible influences are in detail:

- over-charging and accelerated corrosion,
- evolution of hydrogen (water loss, drying-out),
- deterioration of capacity by insufficient charge factor.

The effects depend on amplitude, frequency and wave form of the superimposed AC ripple.

When recharging up to 2.4 Vpc the actual value of the alternating current is occasionally permitted up to 10 A (RMS = effective value) per 100 Ah nominal capacity. In a fully charged state during float charge or standby parallel operation the actual value of the alternating current shall be as low as possible but must not exceed 5 A (RMS) per 100 Ah nominal capacity (see also EN 50272-2 [2]).

The information leaflet “Considerations on service life of stationary batteries” [7] demonstrates how critical the influence of the superimposed AC ripple is with regard to the different lead-acid battery systems “vented” and “VRLA”. Herein, different limits for the superimposed AC ripple (RMS-value) are recommended for float charge operation or standby parallel operation, respectively:

Maximum 2 A per 100 Ah C_{10} for vented lead-acid batteries.
Maximum 1 A per 100 Ah C_{10} for VRLA batteries.

The following effects depend on the frequency.

At > 30 Hz:

- no or negligible conversion of active material because too quick changes of direction of the current, but

- increase of battery temperature,
- increased water loss,
- accelerated corrosion.

At < 30 Hz:

- significant conversion of active material because slow changes of direction of the current and therefore
- lack of charge and
- consumption by cycling.

Lack of charge can occur especially if the portion of negative half-waves exceeds the portion of positives, or if the shape of the wave is distorted toward higher amplitudes of the negative half-waves. Increasing the float voltage by approx. 0.01 up to 0.03 Vpc can help in those cases. But, this should be a temporary measure only.

Highest matter of concern should be the exclusion of too high superimposed AC ripples by the appropriate design of the equipment from the beginning, or the immediate detection of reasons for their occurrence (e.g. by a defective capacitor) later on and corrective actions.

6.3 Float Voltage Deviation

- The individual cell or block float voltages may deviate within a string from the average value 2.23 or 2.25 Vpc, respectively. The following table 8 gives an overview about all the battery types and their variations from the average value under float charge conditions.

2 V-cells	4 V-blocks	6 V-blocks	10 V-blocks	12 V-blocks
+0.1/-0.05	+0.14/-0.07	+0.17/-0.09	+0.22/-0.11	+0.24/-0.12

Table 8: Permissible float voltage deviation from the set average value 2.23 or 2.25 Vpc, respectively

From that, the deviation ranges result as shown in table 9.

	2 V	4 V	6 V	10 V	12 V
OPzS OGi Energy Bloc	2.18-2.33	4.39-4.60	6.60-6.86	11.04-11.37	13.26-13.62
GroE	2.18-2.33	--	--	--	--
OCSM	2.20-2.35	--	--	--	--

Table 9: Permissible range of the float voltage in Vpc. Reference value is the given average value 2.23 or 2.25 Vpc, respectively, acc. to chapter 6.1.

6.4 Charging Times

- The constant current – constant voltage (IU) charging mode is the most appropriate to achieve a very long service life to vented lead-acid batteries. The following diagrams give guide values of time required to recharge a battery at float voltage or enhanced voltage (Boost charge) up to 2.40 Vpc (at 20 °C) depending on depth of discharge (DOD) and initial current.

- How to interpret the diagrams:

  At voltages higher than the float charge voltage, an automatic switch down to the lower float voltage level follows after having reached the initial U-constant level.

  Example:

  IU-charging with 2.40 Vpc. If the voltage has reached 2.40 Vpc, the voltage will be switched down to 2.23 Vpc or to 2.25 Vpc for OCSM. Keeping the voltage at 2.40 Vpc results in clearly shorter recharging times.

  Parameters:

  - Charge voltage 2.23, 2.3 and 2.4 Vpc
  - Charging current 0.5, 1.0, 1.5 and 2.0 • I_{10}
  - Depth of discharge (DOD) 25, 50, 75 and 100% C_{10}

  Different DODs obtained by different discharge rates:
  25%: 10 minutes,
  50%: 1 hour,

75%: 3 hours and
100%: 10 hours.

Higher currents will not lead to relevant gain of recharging time. Lower currents will prolong the recharging time significantly.

See fig. 7 and 8 as examples for how to use the diagrams. A survey of all available diagrams can be found in appendix 1.

Fig. 7: 2.23 Vpc, 1 • I_{10}. A battery discharged to 50% DOD would be re-chargeable to 80 % available capacity within 4 hours. A full re-charge would need up to 48 hours.

Fig. 8: 2.40 Vpc, 1 • I_{10}. The same battery discharged to 50% DOD would be recharged to 80% within 3.7 hours but full re-charged within 20 hours.

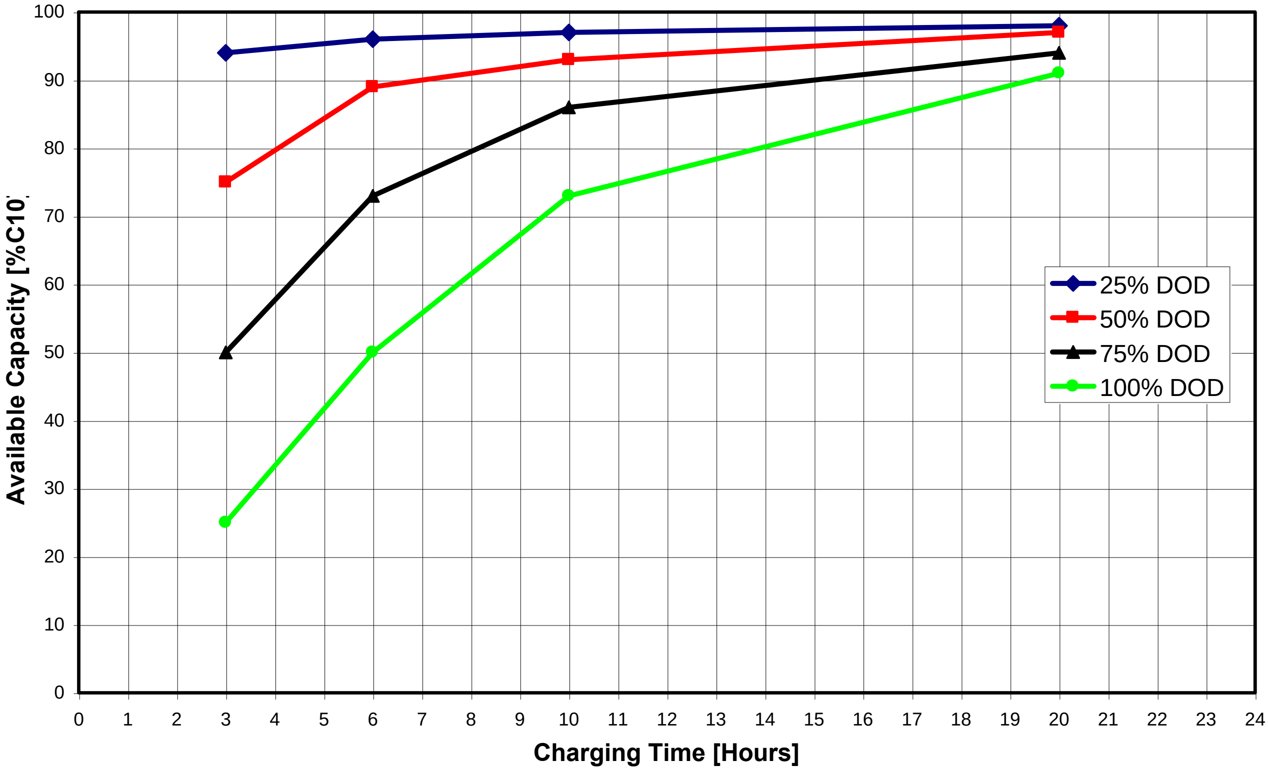


Fig. 7: Available Capacity vs. Charging Time at 2.23 Vpc, Charging Current 1 • I_{10}, DOD = Depth of Discharge

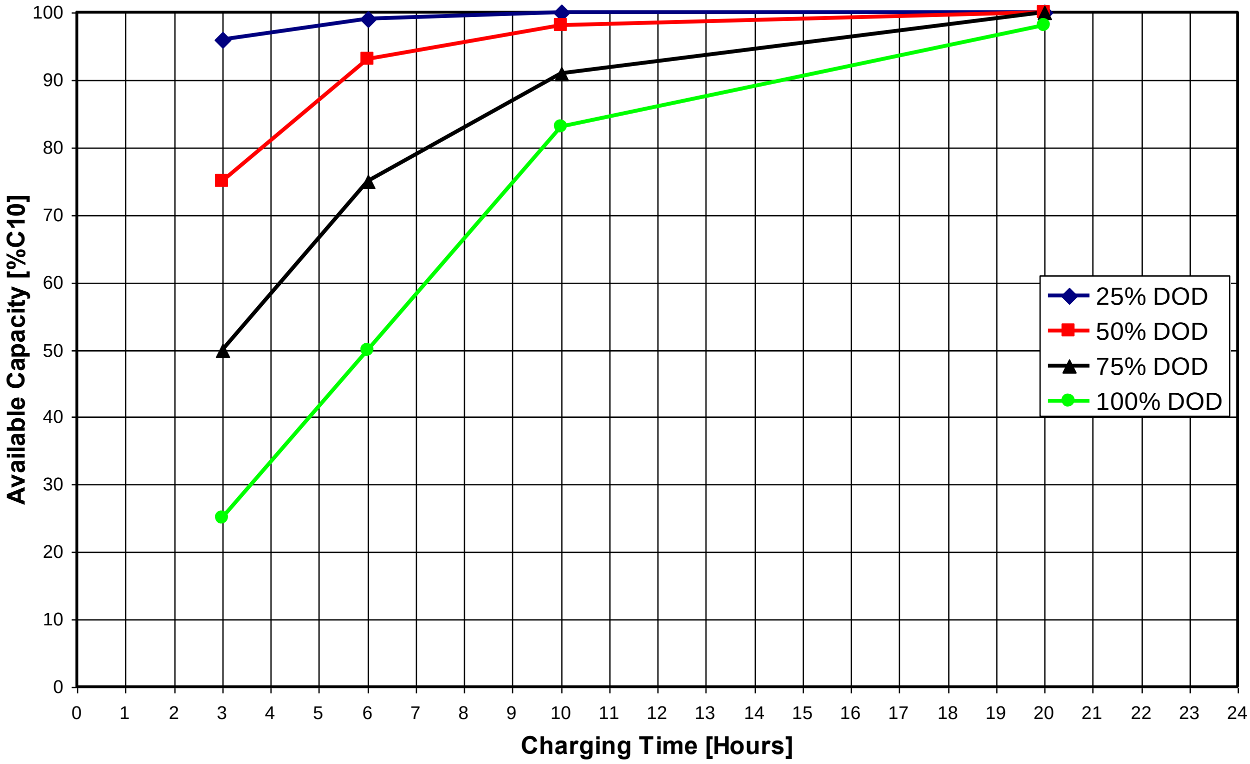


Fig. 8: Available Capacity vs. Charging Time at 2.40 Vpc, Charging Current 1 • I_{10}, DOD = Depth of Discharge

6.5 Efficiency of Re-Charging

6.5.1 Ah-Efficiency

Definition: $$\text{Ah-Efficiency} = \frac{\text{Discharged Ah}}{\text{Re-charged Ah}}$$

Reciprocal value = Charge coefficient (re-charged Ah/discharged Ah)

Normal charge coefficients (pre-set charging time, for instance, 24 hours):

1.20 (discharge rate 10 hours)
1.25 (discharge rate 1 hour)
1.30 (discharge rate 10 minutes)

Ah-efficiency = 1/1.20 …1/1.30 = 83%…77%

Explanations:
The necessary charge coefficient increases with increasing discharge rate (as the depth of discharge (DOD) decreases). Thus, because ohmic losses, heat generation by recombination etc. are relatively same for a given charging time.

6.5.2 Wh-Efficiency

In addition to item “Ah-Efficiency”, average voltages during discharge and re-charging have to be taken into account.

Definition: $$\text{Wh-Efficiency} = \frac{\text{Discharged Ah} \bullet \text{Average Voltage Discharge}}{\text{Re-charged Ah} \bullet \text{Average Voltage Recharge}}$$

Example:
Discharge: Battery C_{10} = 100 Ah
10h discharge, rate: I_{10} → discharged: C_{10} = 100 Ah (100% DOD)

Average voltage during C_{10}-discharge: 2.0 Vpc (estimated)

Recharging: IU-Charging 2.23 Vpc, 1• I_{10}

Expected re-charging time (incl. charge coefficient 1.20): 32 hours

Estimate for average voltage during re-charging: The voltage increases from 2.1 Vpc to 2.23 Vpc during 9 hours → average 2.16 Vpc.

The voltage is constant at 2.23 Vpc for (32-9) hours = 23 hours.

Estimated average voltage during 32 hours: 2.21 Vpc

$$\text{Wh-efficiency} = \frac{100\text{ Ah} \cdot 2.0\text{ Vpc}}{120\text{ Ah} \cdot 2.23\text{ Vpc}} = 0.754 = 75\ \%$$

6.6 Equalizing Charge

Because it is possible to exceed the permitted load voltages, appropriate measures must be taken, e.g. switch off the load.

Equalizing charges are required after deep-discharges and/or inadequate charges or if the individual cell or block voltages are outside the specified range as shown in tables 8 and 9, respectively, in chapter 6.3.

They have to be carried out as follows:

- Up to 72 hours at max. 2.40 Vpc.
- The charge current is unlimited up to achieving U-constant.
- The cell / block temperature must never exceed 55°C. If it does, stop charging or switch down to float charge to allow the temperature to decrease.

Classic-Solar-batteries with system voltages ≥ 48 V

Every one to three months:

Method 1: IUI

IUI-phase = up to voltages from 2.35 to 2.40 Vpc at 20°C

U-phase = until switching at a current of 1.2 A/100 Ah to the second I-phase.

I-phase = 1.2 A/100 Ah for 12 hours.

Method 2: IUI (pulsation)
I-phase = up to voltages from 2.35 to 2.40 Vpc at 20°C
U-phase = until switching at a current of 1.2 A/100 Ah to the second I-phase (pulsed)
I-phase = charging of 2 A/100 Ah for 8-12 hours where the pulses are 15 min. 2 A/100 Ah and 15 min. 0 A/100 Ah.

Attention: Consumers to be disconnected eventually because increasing voltage during the second I-constant-phase!

6.7 Discharge, Capacity Tests

6.7.1 General Items

- Discharge must not be continued below the final discharge voltage acc. to the equivalent discharge current.

- Deeper discharges must not be carried out unless specifically agreed with GNB Industrial Power.

- Recharge immediately following a full or partial discharge (see specifics in chapter 6.8.2, sub-points "Charging" and "Operating in Controlled Partial State of Charge (cPSOC)").

6.7.2 Capacity Tests

- It must be guaranteed that the battery is fully charged before the capacity test. Regarding batteries being in operation already, an equalizing charge must be carried out in case of any doubt.

- Vented lead-acid batteries are delivered filled and charged or unfilled and charged (dry, pre-charged). For the last, in general a full charge is ensured by a commissioning carried out properly.
  Filled and charged and just installed vented batteries show a lack of capacity due to transport and storage. The degree of self-discharge depends on duration and ambient temperature. An estimate is possible roughly only by the rest voltage. Therefore, a specific refreshing charge is important in case of any acceptance tests at site immediately after the installation of a system (see for this "5. Commissioning").

- If possible, the total battery voltage and the single voltages shall be measured in both, float charge operation and open circuit.

- Capacity tests should be carried out acc. to IEC 60896-11 [8]. The voltage of the single cells or blocks shall be recorded automatically or measured by hand. In the last case, the values shall be recorded at least after 25 %, 50 % and 80 % of the expectable discharge time, and afterward in reasonable intervals so that the final discharge voltage can be included.

- The test shall be ended if one of the following criteria is fulfilled, whichever comes first:

  - The battery voltage has reached n • U_f [Vpc], with n = number of cells per string and U_f = final discharge voltage per cell.

    Example:
    U_f = 1.75 Vpc, n = 24 cells,
    battery voltage = 24 cells • 1.75 Vpc = 42 V

  - The weakest cell is fallen down to
    U_{min} = final discharge voltage U_f [Vpc] – 0.2 V

    Example:
    Final discharge voltage U_f = 1.75 Vpc. Therefore, the weakest cell may have: $U_{min} = U_f - 0.2\text{ V} = 1.55\text{ V}$.

Single cells and blocks must be handled from different points of view, because statistics plays a role in case of blocks. Therefore, the following baselines results for calculations:

Minimum permitted voltage (U_{min}) per single cell:
$U_{min} = U_f$ [V/cell] – 0.2 V

Minimum permitted voltage (U_{min}) per block:
$U_{min} = U_f$ [V/block] - $\sqrt{n} \bullet 0.2$ V

(U_f = final discharge voltage, n = number of cells)

Therefore, the following values result:

2 V	4 V	6 V	10 V	12 V
- 0.2	- 0.28	- 0.35	- 0.45	- 0.49

Tab. 10: Voltage tolerances at the end of discharge

Example:
12 V block battery
Final discharge voltage $U_f = 1.75$ Vpc
Final discharge voltage per block: $U_f = 10.50$ V
Calculation: 10.50 V – 0.49 V = 10.01 V
Minimum permitted voltage per block: $U_{min} = 10.01$ V

- The initial temperature is conclusive for the correction of the test result. It shall be between 15 and 35 °C acc. to IEC 60896-11 [8] .

  Proceeding:

  The test results in a measured capacity

  C [Ah] = I [A] • t [h]

  Then, the temperature corrected capacity $C_{corr.}$ [Ah] results in

  $$C_{corr.} = \frac{C}{1 + \lambda\,(\vartheta - 20)} \quad \text{with}$$

  temperature coefficient $\lambda = 0.006$ for tests of $> C_3$ or
  0.01 for tests of $\leq C_3$, respectively,
  initial temperature ϑ in °C.

- There are no regulations regarding the frequency of capacity tests to be carried out. The user can decide as he wants. But, testing too frequently doesn’t make sense, because the result reflects only a momentary state of the battery anyway. Extreme testing could be equivalent to cycling.

  Following an example for a conceivable proceeding in case of a OPzS-battery (service life 15 to 20 years at 20 °C):

  first test after 1 or 2 years *);
  after that, every 3 to 5 years;
  annual as soon as the capacity begins to drop continuously.

*) Instead of the first test after 1 or 2 years it can be also the acceptance test after the commissioning

6.8 Cyclical Operation

6.8.1 General Items

Vented lead-acid batteries can be used also in discharge-charging-mode (a cycle consists of a discharge and a re-charging).

Classic-Solar-batteries (especially EnerSol T, OPzS Solar) are optimized for cyclical application.

Following the numbers of cycles for different battery types:

GroE: 200 cycles *)
OGi, Energy Bloc: 600 cycles *)
OPzS, OPzS-Block, OCSM: 1500 cycles *)

EnerSol: up to 250 cycles *)
EnerSol T: 2000 cycles *)
OPzS Solar: Cells: 2800 cycles *)
≥ 3000 cycles **)
Blocks: 2000 cycles *)

*) Discharge/re-charging conditions acc. to IEC 60896-11 [8]: 20 °C, discharge for 3 h at a current of $I = 2.0 \bullet I_{10}$. This is equivalent to a depth of discharge (DOD) of 60% C_{10}. IU-charging at 2.4 Vpc.
**) 20 °C, depth of discharge (DOD) 60% C_{10}, IUI-charging. Details on request.

The possible numbers of cycles depends on different parameters, i.e. sufficient re-charging, depth of discharge (DOD) and temperature.

Deeper discharge (higher DOD) results in a lower number of cycles because the active material is much more stressed and stronger re-charging is necessary (corrosion!). Therefore, lower DODs results in higher numbers of cycles. See figures 9 to 13 for details.

The correlation between DOD and number of cycles is not always exact proportional. It depends also on the ratio amount of active material versus amount of electrolyte.

With regard to influence of temperature on number of cycles see chapter 6.10.

Note:
The cycle life (calculated number of years with a specified daily DOD) can never exceed the service life! The cycle life is rather less than the service life due to non-expectable influences.

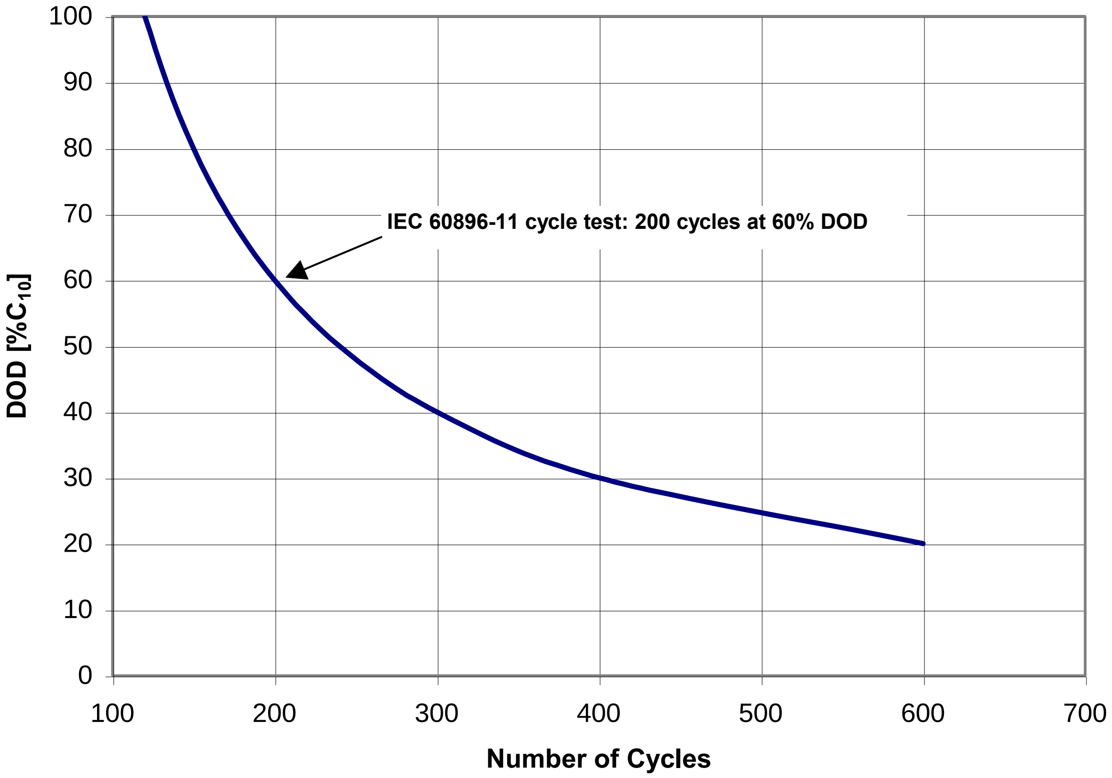


Fig. 9: GroE – Number of Cycles vs. Depth of Discharge (DOD)

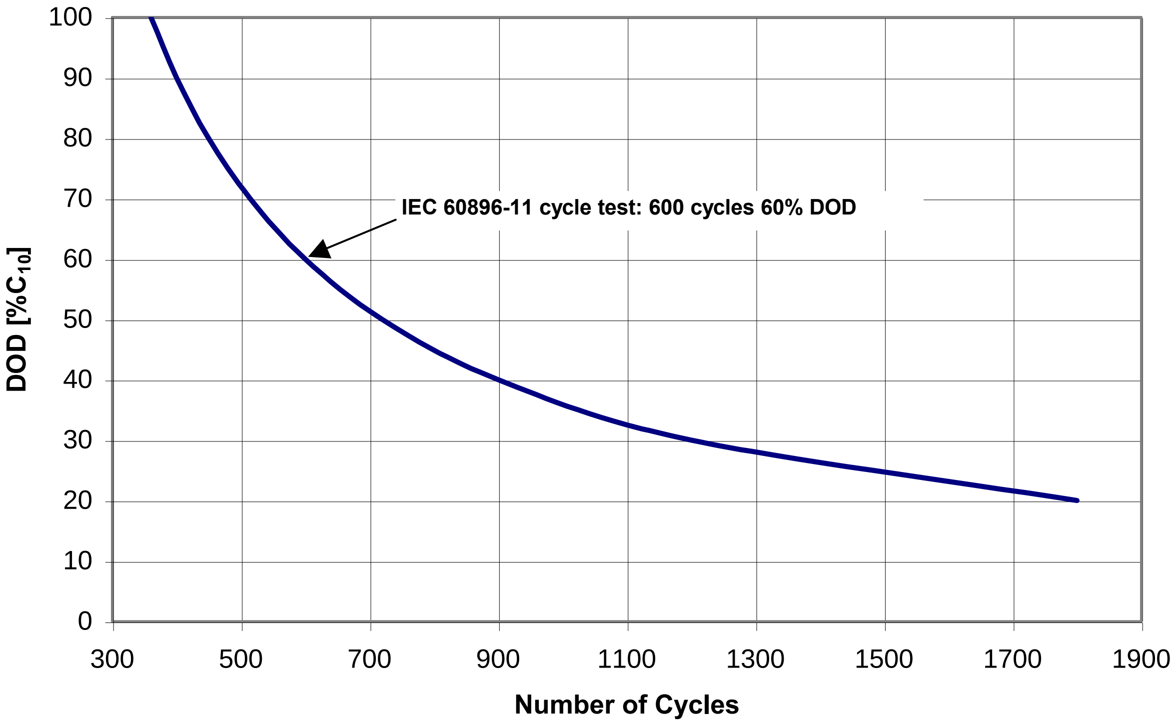


Fig. 10: OGi, Energy Bloc – Number of Cycles vs. Depth of Discharge (DOD)

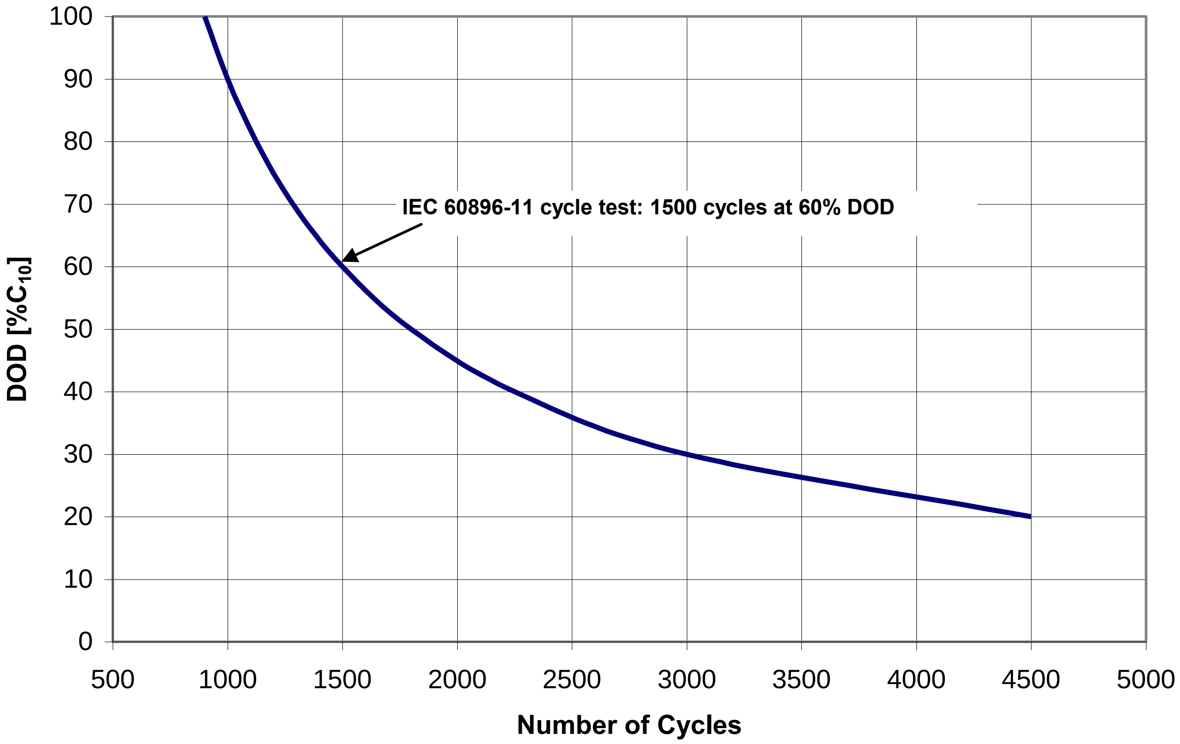


Fig. 11: OPzS, OPzS-Block - Number of Cycles vs. Depth of Discharge (DOD)

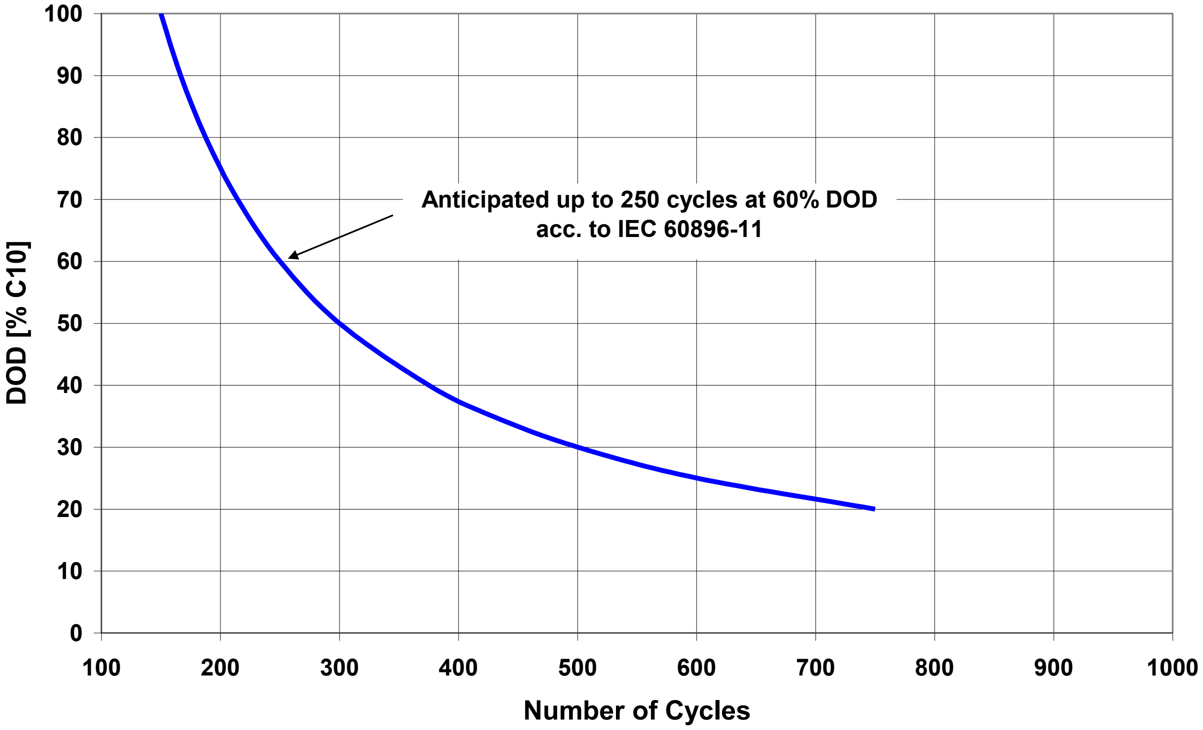


Fig. 12: EnerSol - Number of Cycles vs. Depth of Discharge (DOD)

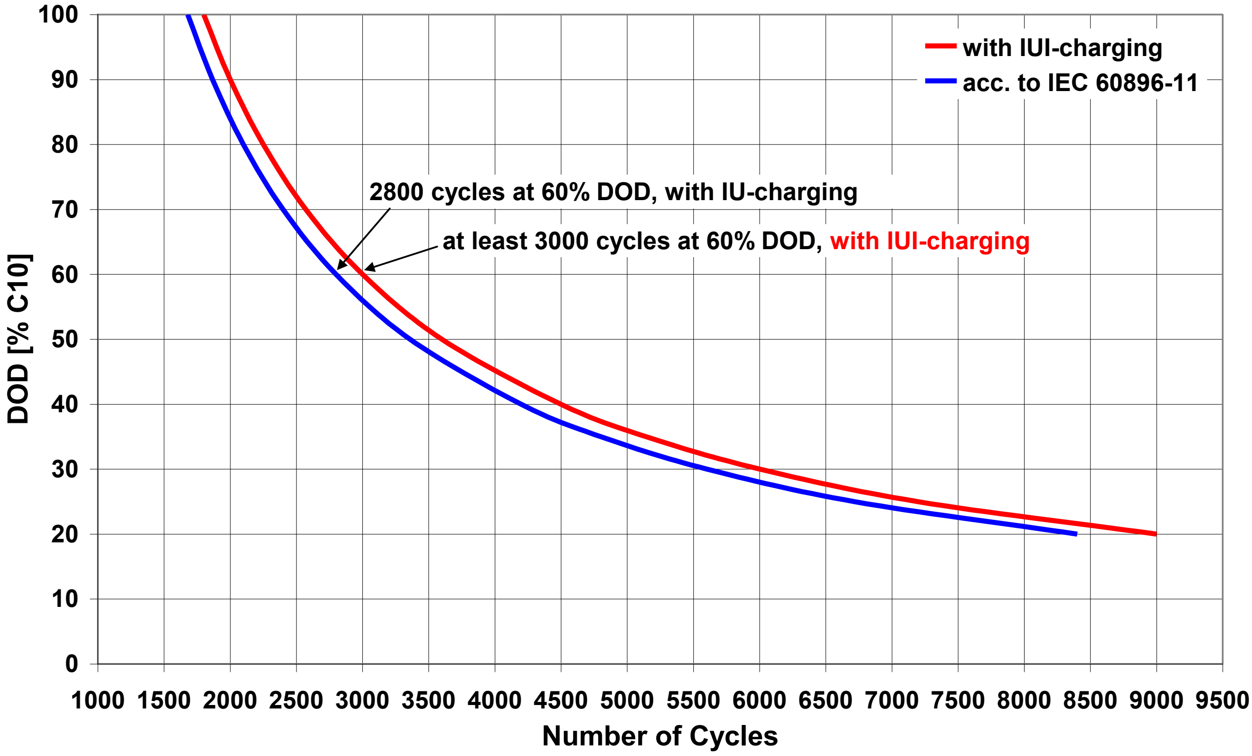


Fig. 13a: OPzS Solar-Cells - Number of Cycles vs. Depth of Discharge

(DOD)

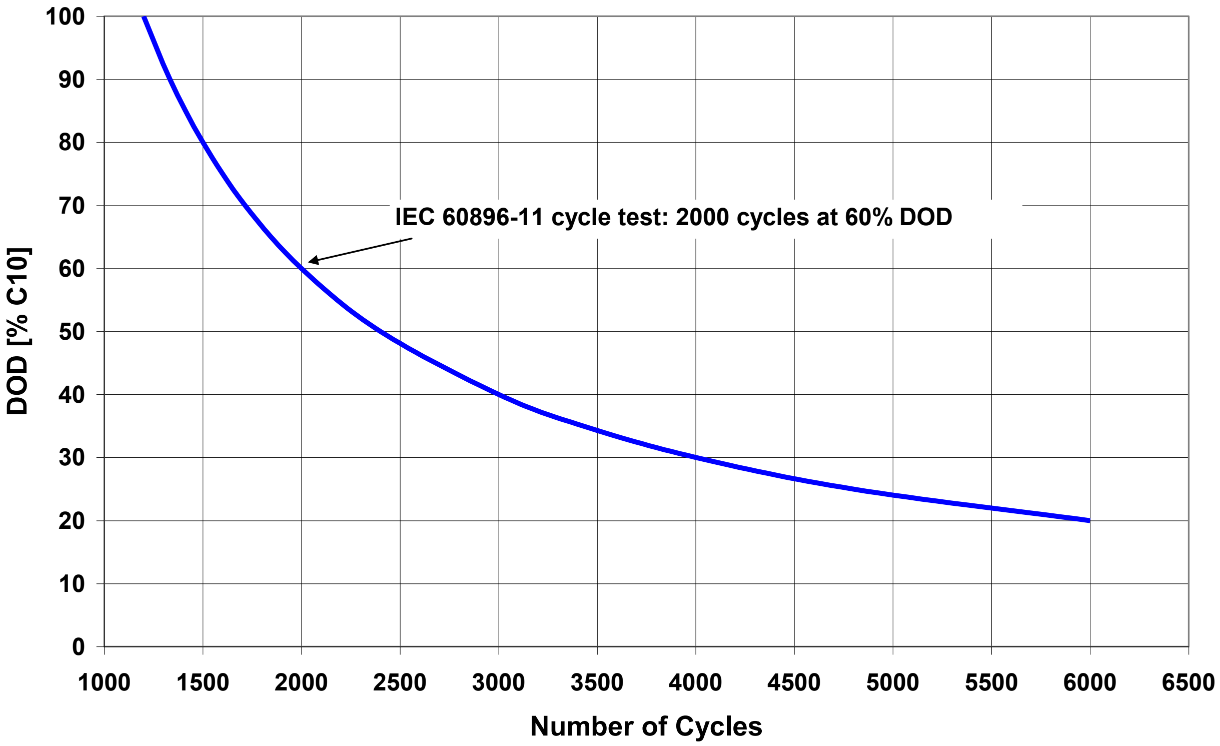


Fig. 13b: OPzS Solar-Blocks, EnerSol T - Number of Cycles vs. Depth of Discharge (DOD)

6.8.2 Special Considerations about Classic-Solar-Batteries

- Solar-Module(s)
  - Sufficient power is necessary for charging the battery
  - Realization of an optimal installation (criteria, e.g.: alignment, angle of inclination, shading, possible pollution).

- Charge Controller
  - Designed to control over-charging
  - Designed to prevent deep discharge
  - Optional temperature correction
  - Critical to battery life (i.e. voltage settings)

- Battery Sizing: General Considerations
  - Minimize voltage drop

  - Use oversized cables
  - Locate battery and load closed to PV panel
  - Choose a large enough battery to store all available PV current
  - Ventilate or keep battery cool, respectively, to minimize storage losses and to minimize loss of life
  - Is a Diesel generator available for boost charge ?

- Battery Sizing: Details

  - Hours/days of battery reserve requested?
  - Final discharge voltage of the battery?
  - Load/profile: Momentary, running, parasitic current?
  - Ambient temperature: maximum, minimum, average?
  - Charging: voltage, available current, time? “Balance” of withdrawn and re-charged Ampere-hours?
  - Optimum daily discharge: $\leq$ 30% of C_{10}, typically 2 to 20 % C_{10}
  - Recommended maximum depth of discharge during long-duration discharges $\geq$ 48 h: 80%. This is equal an addition of 25% to the calculated capacity. e.g. C_{100} or C_{120}.
    An addition of 25% is also recommended if more than the C3-capacity is withdrawn and if the PV-energy for re-charging is insufficient and other sources, e.g. Diesel generator, are not available

- Battery Sizing: Guideline

  - Standard IEEE P1013/D3, April 1997 [9] inclusive worksheet and example

- Battery Sizing: Summary

  - System must be well designed.
  - System must fulfill the expectations throughout the year!
  - Right design of panel, charge controller and battery!
  - Load and sun light must be in equilibrium (how many hours/days in summer/winter ?)
  - The whole system with as less as possible maintenance, especially in rural areas

- Temperature Difference

The battery installation shall be done on such a way that temperature differences between individual cells/blocks do not exceed 3 degree Celsius (Kelvin).

- Charging

  The charging of Classic-solar batteries shall be carried out acc. to the operating instructions which goes with this.

  Solar batteries have to be operated also at States-of-Charge (SOC) less than 100% due to seasonal and other conditions, for instance (acc. IEC 61427 [10]):

  Summer: 80 to 100% SOC,
  Winter: down to 20% SOC.

  The charge voltage must be increased or an equalizing charge must be given if the nominal electrolyte density is not achieved at least monthly.

  Overall, this corresponds to operating in uncontrolled partial state of charge. The acc. to IEC 60896-11 [8] reported numbers of cycles may not be reached in certain circumstances.

- Operating in “Controlled Partial State of Charge” (cPSOC)

  The cycle life during daily cyclical application can be increased when working in PSOC if the installation and operating instructions, a maximum depth of discharge 80% C_{10} and following special operating conditions are fulfilled:

  1. With daily recharge to 90% C_{10} after discharge:

     At least weekly: Full recharge plus equalizing charge at 2.4 Vpc for at least 12 hours (better 24 hours) and a current of at least 20 A /100 Ah C_{10} (max. 35 A/100 Ah C_{10}).

  2. With daily recharge to 95% C_{10} after discharge:

     At least every 2 weeks: Full recharge plus equalizing charge at 2.4 Vpc for at least 12 hours (better 24 hours) and a current of at least 20 A /100 Ah C_{10} (max. 35 A/100 Ah C_{10})

The periodic full recharge plus equalizing charging is necessary in order to overcome so-called sulfation and to bring the battery back in an optimal initial state. The cycle life will be increased with regard to the published numbers of cycles acc. to IEC 60896-11 [8] because reduced life limiting effects, in particular, positive plate corrosion.

6.9 Internal Resistance R_i

- The internal resistance R_i is determined acc. to IEC 60896-11 [8]. It is an important parameter when computing the size of batteries. A remarkable voltage drop at the beginning of a discharge, especially at high discharge rates equal and less than 1 hour, must be taken into account.

- The internal resistance R_i varies with depth of discharge (DOD) as well temperature, as shown in the following fig. 14 and 15. Hereby, the R_i-value at 0% DOD (fully charged) and 20 °C, respectively, is the base line (R_i-factor = 1).
  The R_i-basic value can be taken from the equivalent catalogue.

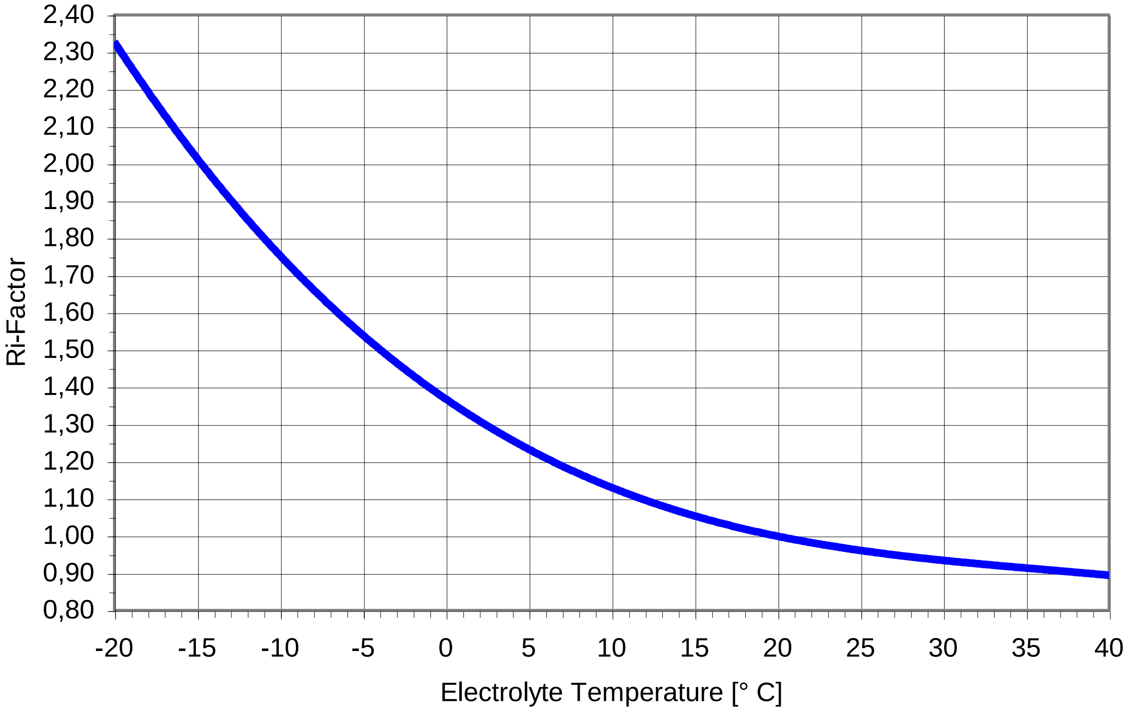


Fig. 14: R_i -Factor vs. Electrolyte Temperature

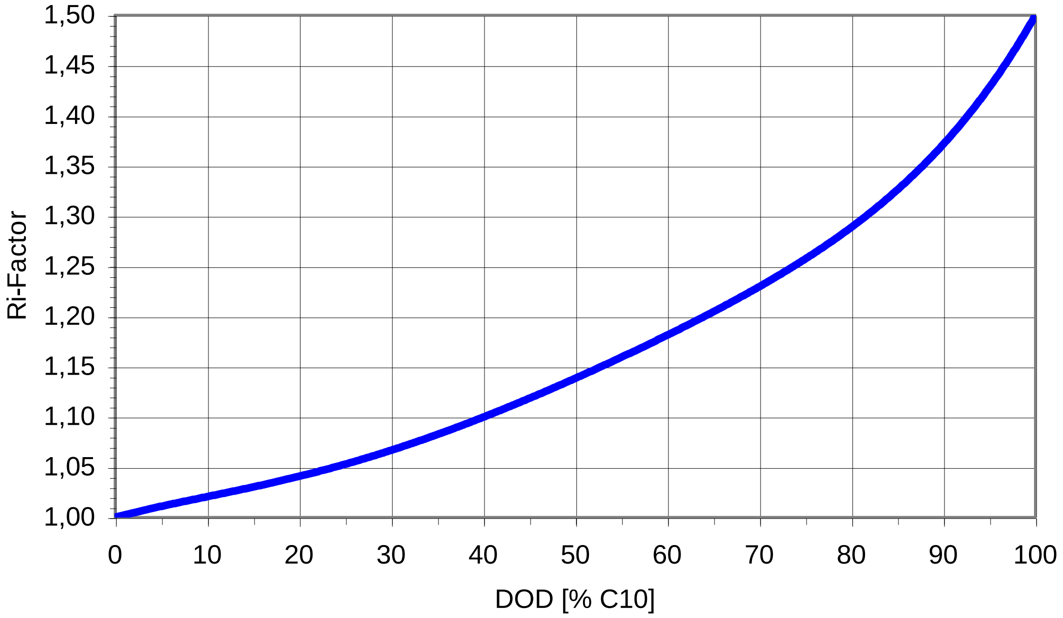


Fig.15: Ri - Factor vs. Depth of Discharge (DOD)

6.10 Influence of Temperature

The design of vented lead-acid batteries allows the use in a wide temperature range from – 20 °C to + 55 °C.

6.10.1 Influence of Temperature on the Electrolyte Density

The electrolyte density depends on the temperature. Higher temperatures reduce, lower temperatures increase the electrolyte density. The equivalent coefficient is – 0.0007 kg/l per K (compare 5.3).

There is a risk at temperatures of approx. less than –5 °C regarding freezing-in of the electrolyte depending on the depth of discharge, see fig. 16.

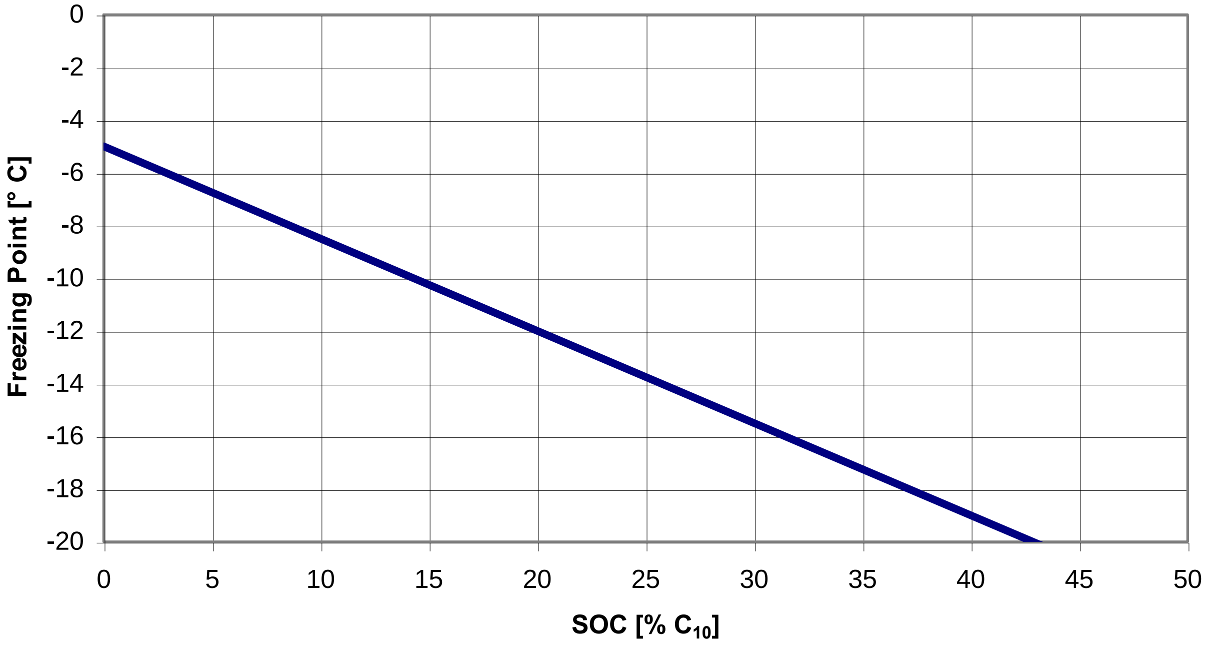


Fig. 16: Electrolyte Freezing Point vs. Sate of Charge (SOC)

6.10.2 Influence of Temperature on Capacity, Service Life and Endurance in Cycles

- 20 °C (25 °C for “Classic-Solar”) is the nominal temperature and the optimal temperature regarding capacity and service life. Lower temperatures reduce the available capacity and prolong the re-charge time. Higher temperatures reduce the lifetime and the number of cycles.

- The battery temperature influences the capacity as shown in fig. 17.

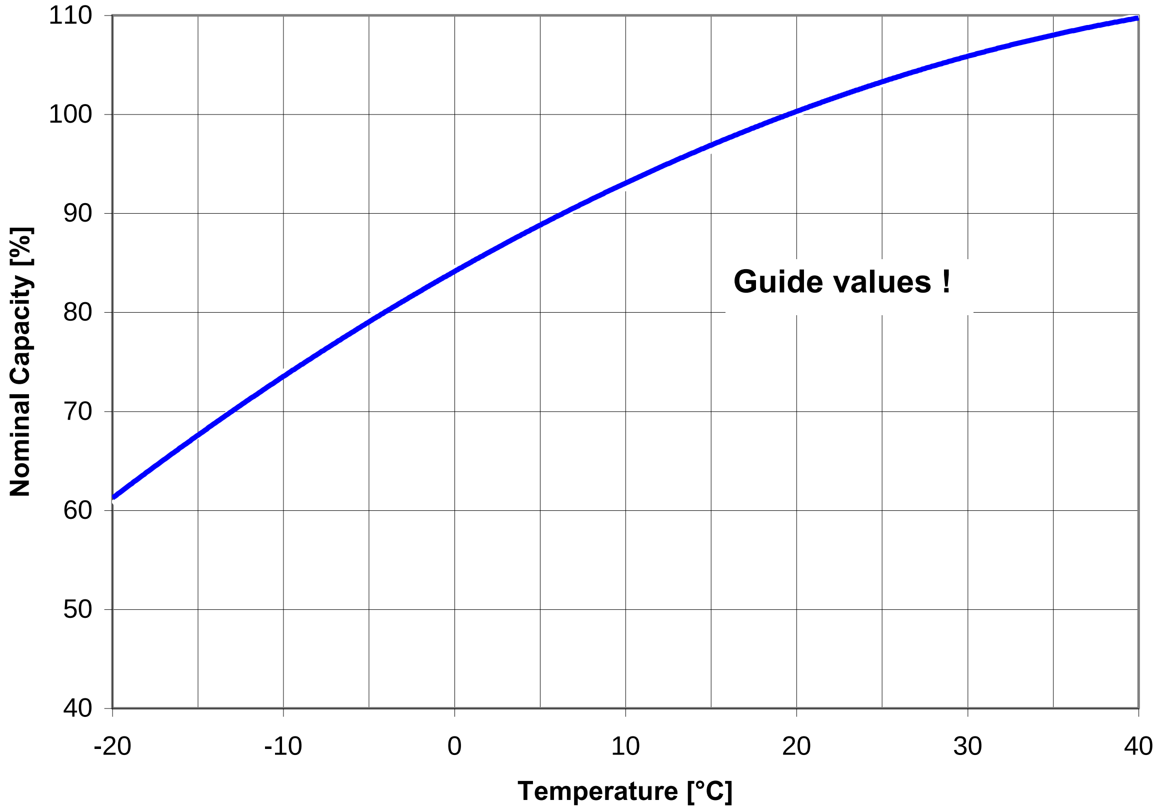


Fig. 17: Nominal Capacity vs. Temperature

- Common service life applied to the nominal capacity, 20 °C and with occasional discharges:

  GroE: 20 to 25 years
  OCSM: 15 to 20 years
  OPzS ≤ 3000 Ah: 15 to 20 years
  OPzS > 3000 Ah: 15 years
  OPzS Block: 15 to 20 years
  OGi: 18 years
  Energy Bloc: 13 to 15 years

  in comparison to the determined design life applied to the nominal capacity and 20 °C:

  GroE: 25 years
  OCSM: 20 years
  OPzS ≤ 3000 Ah: 20 years
  OPzS > 3000 Ah: 15 years
  OPzS Block: 20 years
  OGi: 20 years

Energy Bloc: 15 years

- High temperatures affect batteries' service life acc. to a common rough formula (law of "Arrhenius"):

  The corrosion rate is doubled per 10 °C. Therefore, the lifetime will be halved per 10 °C increase.

  Example: 15 years at 20 °C becomes reduced to 7.5 years at 30 °C

  This is even valid for all batteries with positive grid plate design.

  There are exceptions where the influence doesn't follow the law of "Arrhenius", - that's for OCSM, OPzS and OPzS Block with positive tubular plates. The influence of temperature is less than for other batteries. For instance, an increase of 10 degrees from 20 to 30 °C will cause a life reduction of about 30% only instead of 50%.

  Reasons:

  - Casting of the positive spine frame on high-pressure die-casting machines. Hereby, the injection pressure is 100 bar. That assures a very fine grain structure high resistant to the corrosion process.

  - The active material, but also the corrosion layer is under high pressure by the gauntlets avoiding a growth of corrosion layer as fast as in positive grid plate designs.

  - The spines are covered by an approx. 3 mm layer of active material. Therefore, the spines are not stressed by conversion of active material and electrolyte as much as in grid plates. The conversion occurs mainly in the outer parts of the tubular plates.

Fig. 18 shows the dependency of the service life on the temperature for different lines of products.
Fig. 19 is regarding the influence of temperature on the endurance in cycles (number of cycles). Daily cycles up to 60% DOD C_{10}, typically 5 to 20 % are taken into account. The influence of temperature is not as strong as in float charge operation because negligible corrosion during discharges in comparison to re-charging, but the upper curve in fig. 19 moves closer to the lower curve as longer the duration in fully or nearly fully charged state.

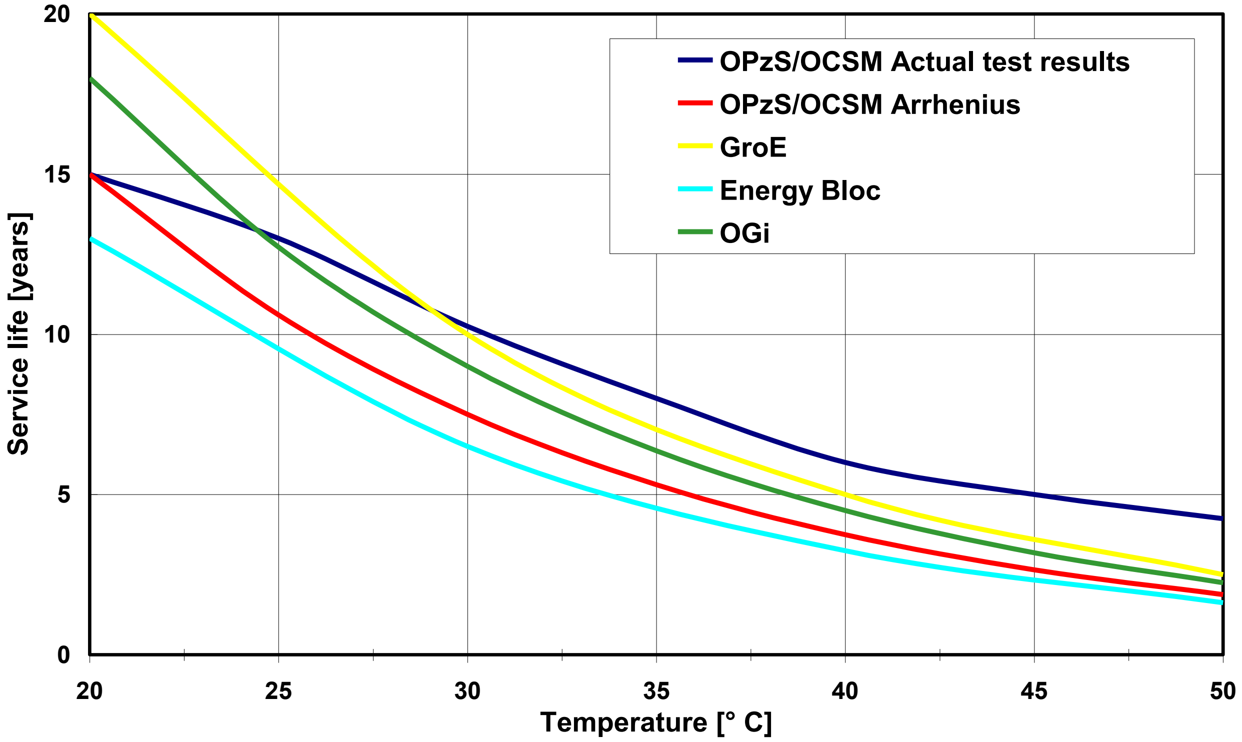


Fig. 18: GroE, OCSM, OPzS, OGi, Energy Bloc – Service Life vs. Temperature. The blue curve is valid in practice.

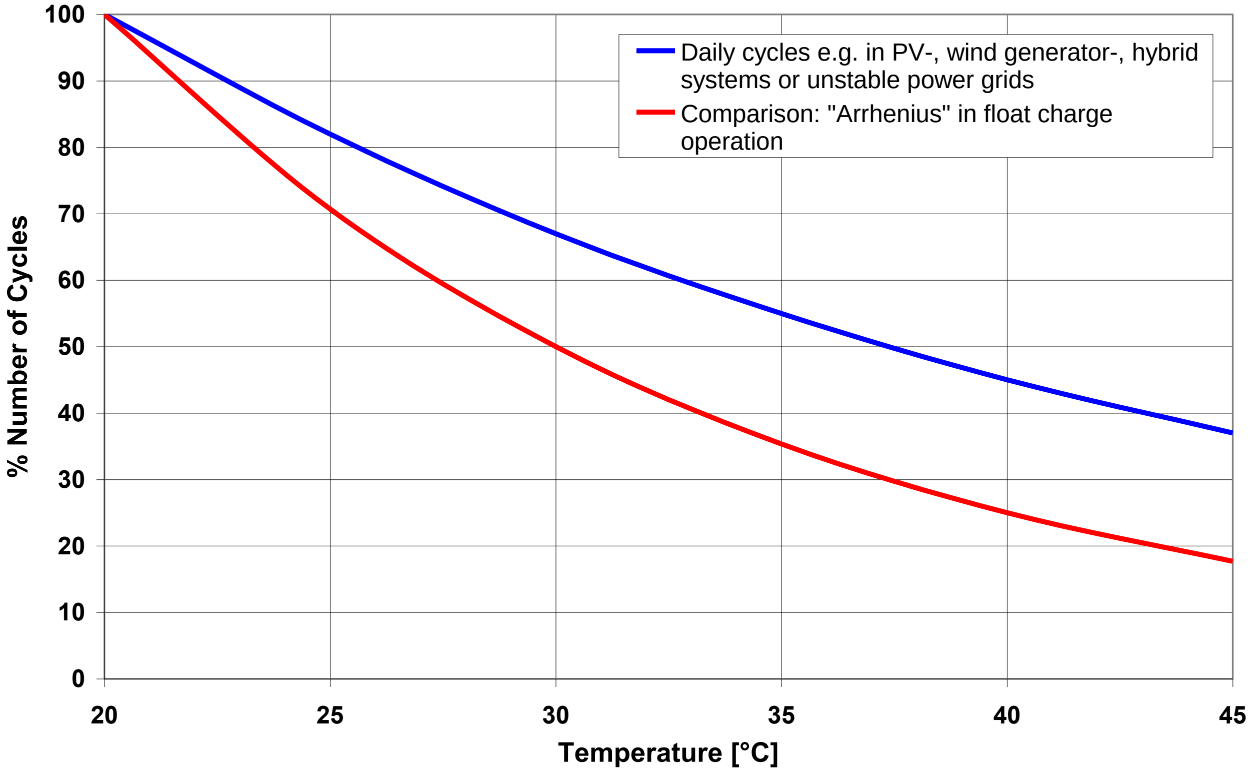


Fig. 19: Blue curve: Endurance in Cycles (in % of Number of Cycles) vs. Temperature; daily DOD max. 60% C_{10}, typically 5 to 20 %

6.11 Maintenance and Checks

6.11.1 General Items and Checks acc. to Operating Instructions

- Periodic inspections and maintenance are necessary regarding:

    - charge voltage and current settings,
    - the discharge conditions,
    - the temperature levels,
    - the storage conditions,
    - the cleanliness of the battery and equipment
    - and other conditions relevant to safety issues and battery's service life (battery room ventilation, for example).

- Periodic discharges can be used to assess the available operating endurance, to detect faulty cells / blocks and aging symptoms of the battery, in order to consider battery replacement in due time.

- Keep the battery clean and dry to avoid leakage currents. Plastic parts of the battery, especially containers, must be cleaned with pure water without additives.

- At least every 6 months measure and record:

    - Battery voltage
    - Electrolyte density, electrolyte temperature and voltage of several cells / blocks (approx. 20%)
    - Battery-room temperature

- Annual measurement and recording:

    - Battery voltage
    - Voltage of all cells / blocks
    - Electrolyte densities and electrolyte temperatures of all cells
    - Battery-room temperature

  Annual visual checks:

    - Screw connections (screw connections without locking devices have to be checked for tightness)
    - Battery installation and arrangement
    - Ventilation

If the cell / block voltages (average float charge voltage at 2.23 or 2.25 Vpc acc. to chapter 6.1) are outside the range as mentioned in table 9 (see chapter 6.3) the service agent should be contacted.
Deviations of the battery voltage from the average value depending on the battery type and the number of cells have to be corrected (see chapter 6.1).

6.11.2 Battery Testers and Battery Monitoring

Sometimes, other methods than capacity tests are offered for checking the state-of-health, state-of-charge or capacity of batteries. This equipment is based on any of the following ohmic methods: conductance, impedance, DC-resistance.

So-called battery testers are portable. Any of ohmic methods as mentioned above can be included in battery monitoring systems. Hereby, monitoring means the system works on-line and is permanently connected to the battery.

Either battery testers or monitoring system, the above mentioned ohmic methods can be used in order to follow up trending of data. But, they can never replace a standardized capacity test.

Thus, because none of the above mentioned methods can supply absolute results. In fact, the results of measurements depend on the concrete method (frequency, amplitude etc.), the operator (battery testers!) and other parameters, i.e. temperature and location of probes on the cells or blocks. For more information, see also [11] and [12].

The following guideline can be used for the interpretation of impedance / conductance / resistance measurements:

- If impedance or conductance measurements are used for VRLA batteries it is recommended to install the battery and keep it for at least two days on float charge. After the two days and a maximum of seven days the first readings should be taken. These readings represent the initial impedance/conductance values for the blocks or cells.

- It is then recommended to take impedance/conductance readings every 6 or 12 months. If the application is considered as very critical in terms of reliability of power supply the readings can be taken more often.

- The interpretation of impedance/conductance values can not end with a conclusion of full capacity, low capacity or no capacity. Therefore the following recommendations can be made:

  - If impedance/conductance values of blocks or cells change more than 35 % to negative direction*), compared to the initial value, a boost charge for 12 hours followed by 2 days on float charge is recommended firstly. The measurement must be repeated. If the values are not decreasing below the 35 % criteria, a capacity test should be carried out for the battery.

  - If impedance/conductance values of blocks or cells measured have a negative deviation*) of more than 35 %, compared to the average value (per battery), a boost charge for 12 hours followed by 2 days on float charge is recommended firstly. The measurement must be repeated. If the values are not decreasing below the 35 % criteria, a capacity test should be carried out for the battery.

  - If no initial values are measured for a battery, only the second method can be applied.

  *) impedance to higher values and conductance to lower values

All impedance/conductance measurements can be compared to each other only if the temperature does not differ more than +/- 2 °C.

For favorable deviations (impedance lower or conductance higher) no activity is needed (unless it complies with low DC float voltage) because this changing is related to the normal capacity increase of batteries put in float charge operation.

If a cell or a block is changed based on impedance/conductance measurement and returned to the manufacturer for investigation it is strongly recommended to write the measured value with permanent ink on the cell or block.

6.11.3 Cleaning of Batteries

- The cell vent plugs must not be removed or opened, but must keep closed the cells [1].
- It is allowed to clean the plastic parts of the battery, especially the cell containers, by water respectively water-soaked clothes only without additives [1].
- After the cleaning, the battery surface has to be dried on a suitable way, for instance, by compressed air or by clothes [1].

7. Recycling, Reprocessing

Lead-acid batteries are recoverable commercial ware. GNB Industrial Power’s factories recycle used lead and see oneself as a part of the entire life cycle of a battery with regard to environmental protection. Contact your GNB Industrial Power representative. He will inform you about further details.

This holds also for used cells / blocks.

The transport of used accumulators is subject to special regulations. Therefore, it is recommended to order a company specialized in packaging and in making out of freight papers.

Details about the transport of used accumulators can be found in the information leaflet of the ZVEI “Taking back of used industrial batteries acc. to the battery decree” [13].

8. List of References

[1] Information leaflet “Cleaning of Batteries” of the working group “Industrial Batteries” in the ZVEI (Central Association of German Electrical and Electronic Manufacturers), Frankfurt/M., edition October 2006

[2] European standard EN 50272-2 “Safety requirements for secondary batteries and battery installations, Part 2: Stationary batteries”, June 2001

[3] Directive 2006/95/EC relating to electrical equipment designed for use within certain voltage limits (so-called “Low Voltage Directive”), amended by the Directive 93/68/EEC, the so-called “CE marking Directive”

[4] B. A. Cole, R. J. Schmitt, J. Szymborski (GNB Technologies): “Operational Characteristics of VRLA Batteries Configured in Parallel Strings”, proceedings INTELEC 1998

[5] Information leaflet “Requirements on electrolyte and topping-up water for lead-acid batteries” of the working group “Industrial Batteries” in the ZVEI (Central Association of German Electrical and Electronic Manufacturers), Frankfurt/M., edition July 1999 (available in German language only)

[6] German standard DIN 41774, part 1 “Semiconductor rectifier equipment with IU-characteristic for the charging of lead-acid batteries – Guidelines”, edition February 1979 (this standard is available in German language only)

[7] Information leaflet “Considerations on service life of stationary batteries” of the working group “Industrial Batteries” in the ZVEI (Central Association of German Electrical and Electronic Manufacturers), Frankfurt/M., edition January 2013

[8] International standard IEC 60896-11 “Stationary lead-acid batteries, Part 11: Vented types – General requirements and methods of test”, first edition December 2002

[9] International standard IEEE P1013/D3: “IEEE Recommended Practice for Sizing Lead-Acid Batteries for Photovoltaic (PV) Systems”, draft April 1997

[10] International standard IEC 61427 “Secondary cells and batteries for photovoltaic energy systems (PVES) - General requirements and methods of test”, second edition 2005-05

[11] B. A. Cole, R. J. Schmitt (GNB Technologies): “A Guideline for the Interpretation of Battery Diagnostic Readings in the Real World”, Battconn ’99

[12] PPT-Presentation “Battery-Testers, -Monitoring, -Management” (GNB Industrial Power, Applications Engineering), latest version

[13] Information leaflet “Taking back of used industrial batteries acc. to the battery decree” of the working group “Industrial Batteries” in the ZVEI (Central Association of German Electrical and Electronic Manufacturers), Frankfurt/M., edition July 2007 (available in German language only)

[14] International standard IEC 62485-2 “Safety requirements for secondary batteries and battery installations - Part 2: Stationary batteries”, June 2010

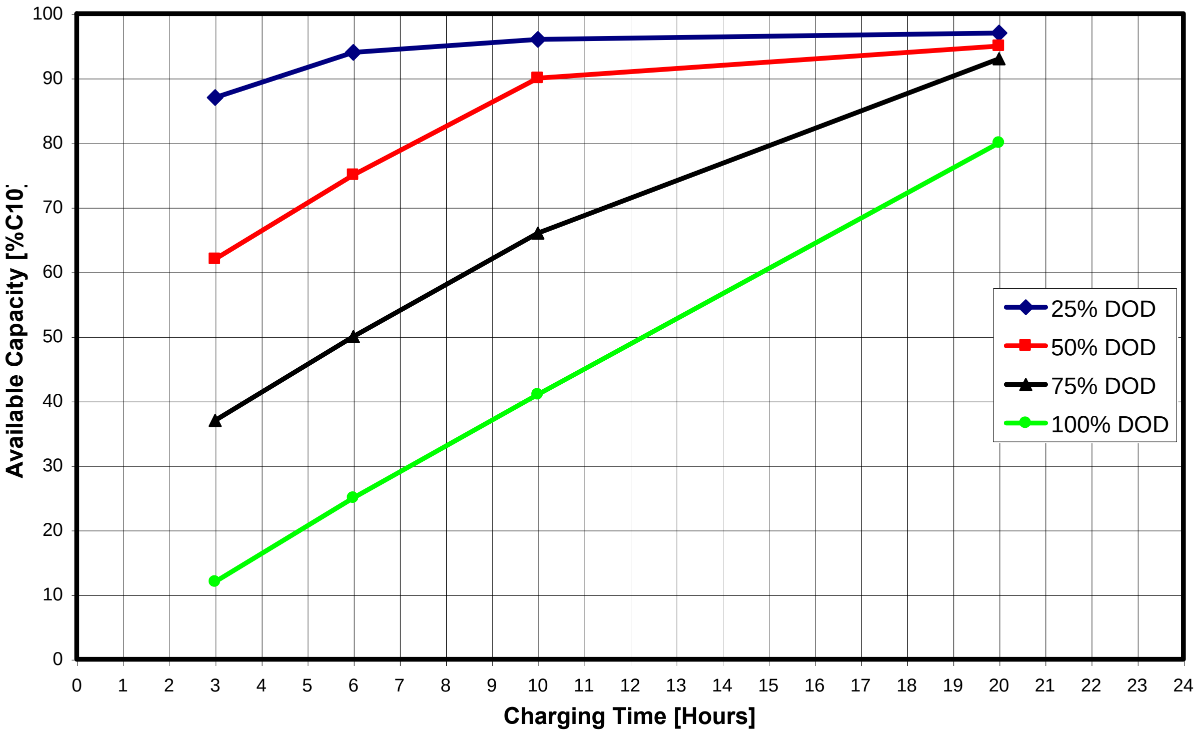


Fig. 20: Available Capacity versus Charging Time at 2.23 Vpc, Charging Current 0.5 • I_{10}, DOD = Depth of Discharge

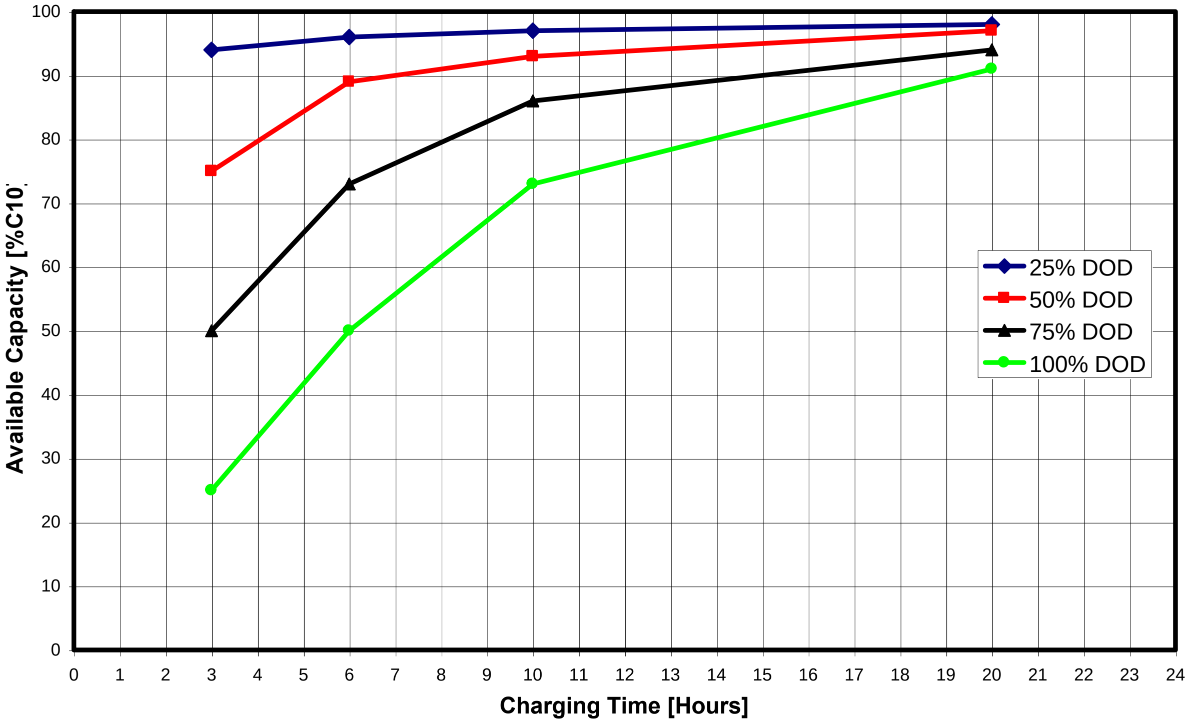


Fig. 21 (same as fig. 7 in chapter 6.4): Available Capacity vs. Charging Time at 2.23 Vpc, Charging Current 1 • I_{10}, DOD = Depth of Discharge

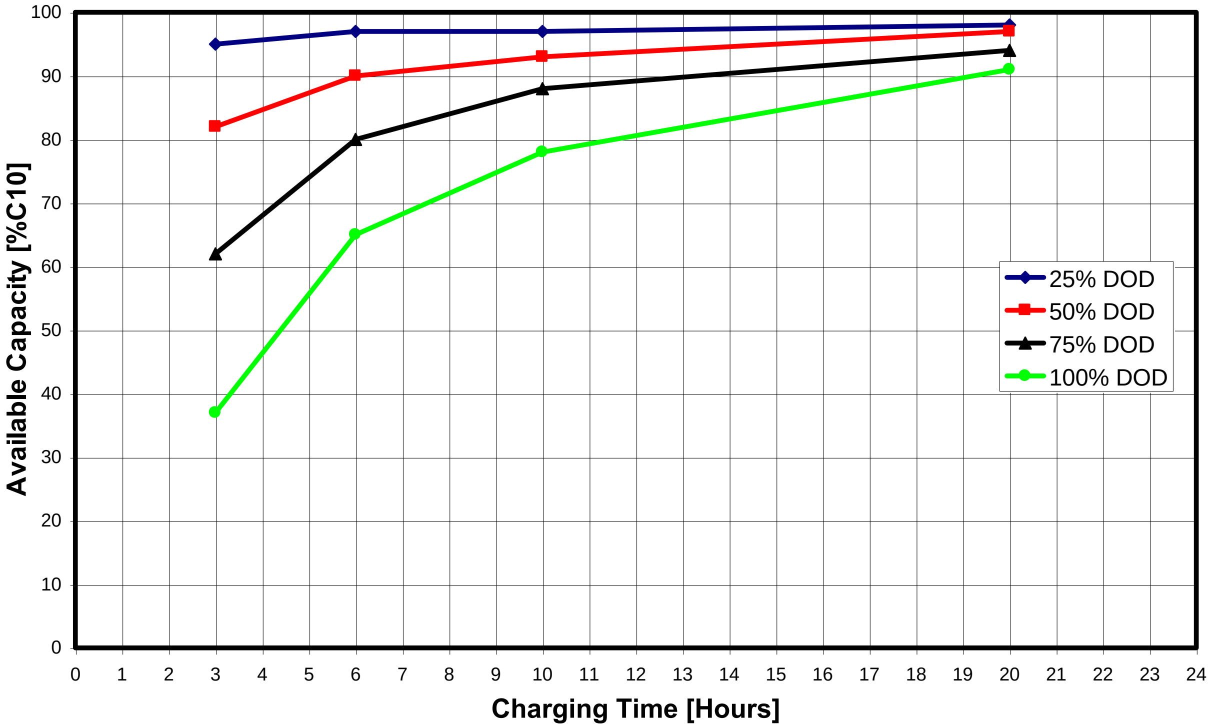


Fig. 22: Available Capacity versus Charging Time at 2.23 Vpc, Charging Current 1.5 • I_{10}, DOD = Depth of Discharge

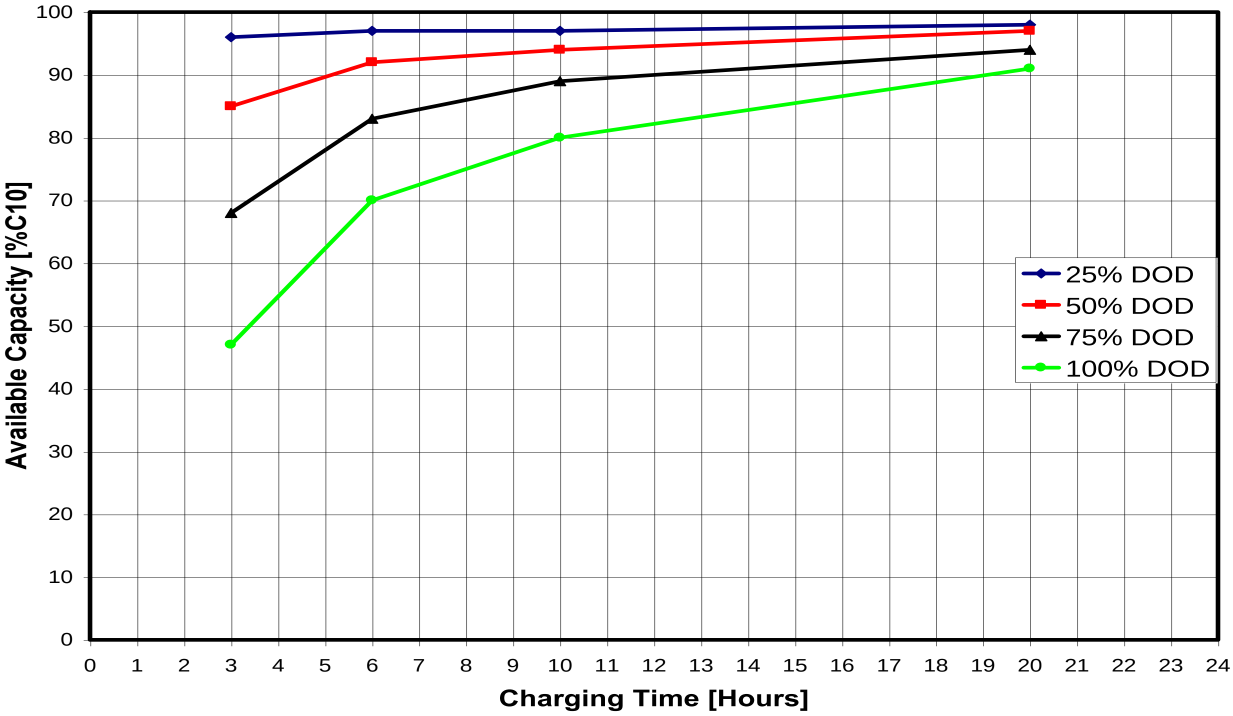


Fig. 23: Available Capacity versus Charging Time at 2.23 Vpc, Charging Current 2 • I_{10}, DOD = Depth of Discharge

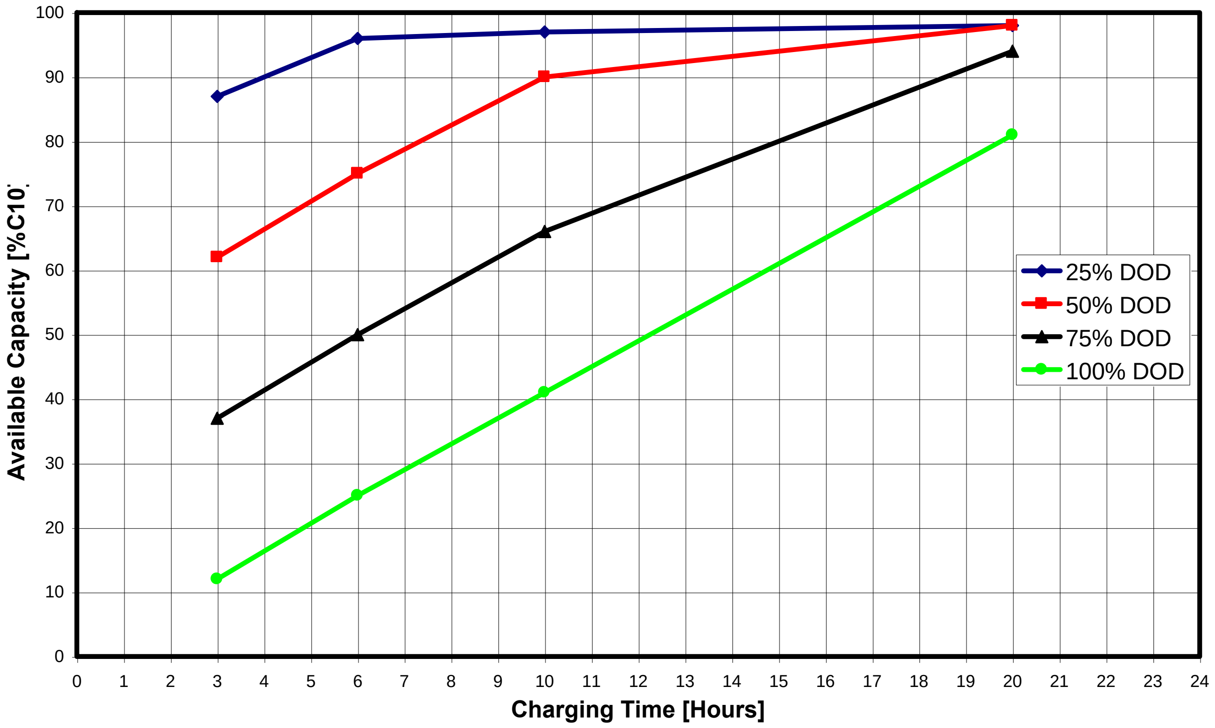


Fig. 24: Available Capacity versus Charging Time at 2.30 Vpc, Charging Current 0.5 • I_{10}, DOD = Depth of Discharge

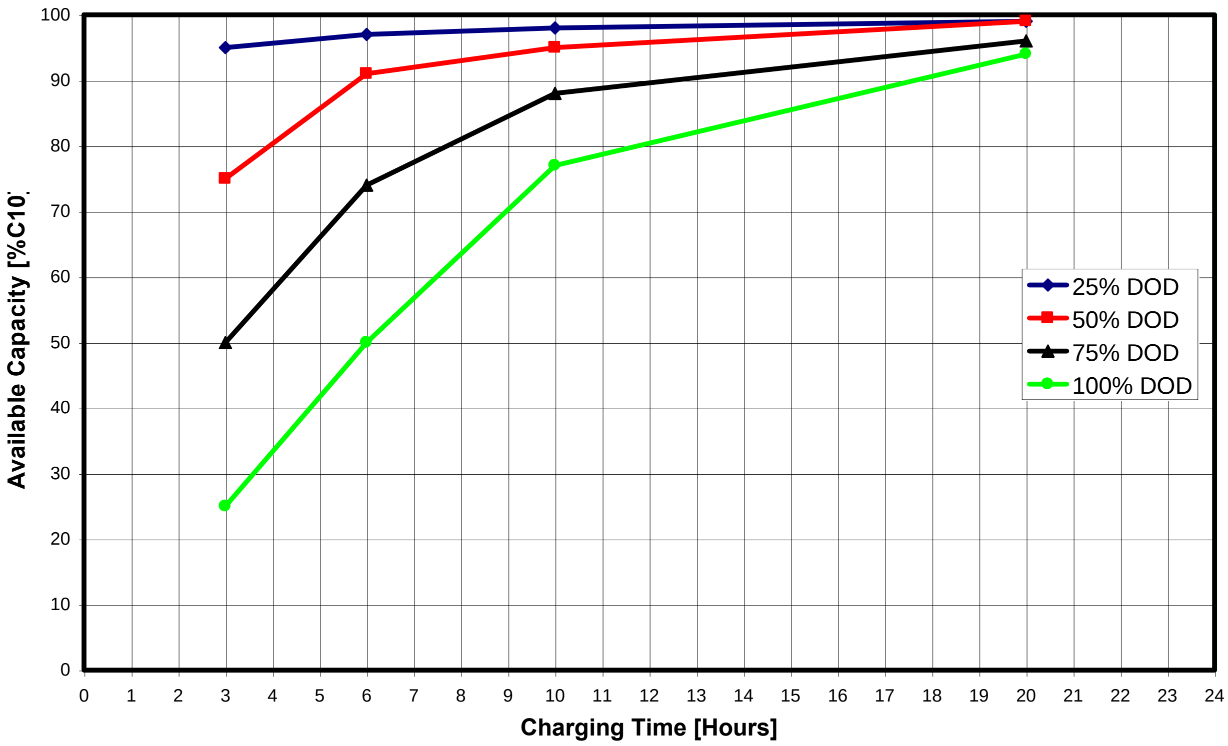


Fig. 25: Available Capacity versus Charging Time at 2.30 Vpc, Charging Current 1 • I_{10}, DOD = Depth of Discharge

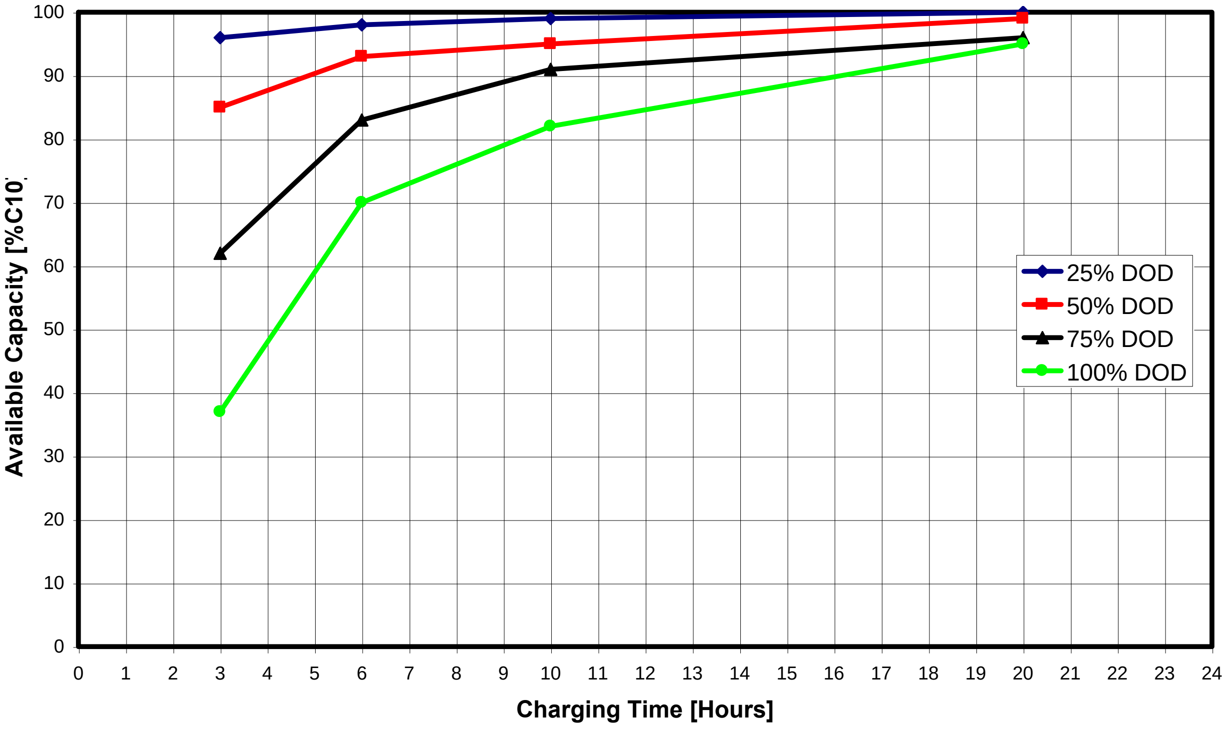


Fig. 26: Available Capacity versus Charging Time at 2.30 Vpc, Charging Current 1.5 • I_{10}, DOD = Depth of Discharge

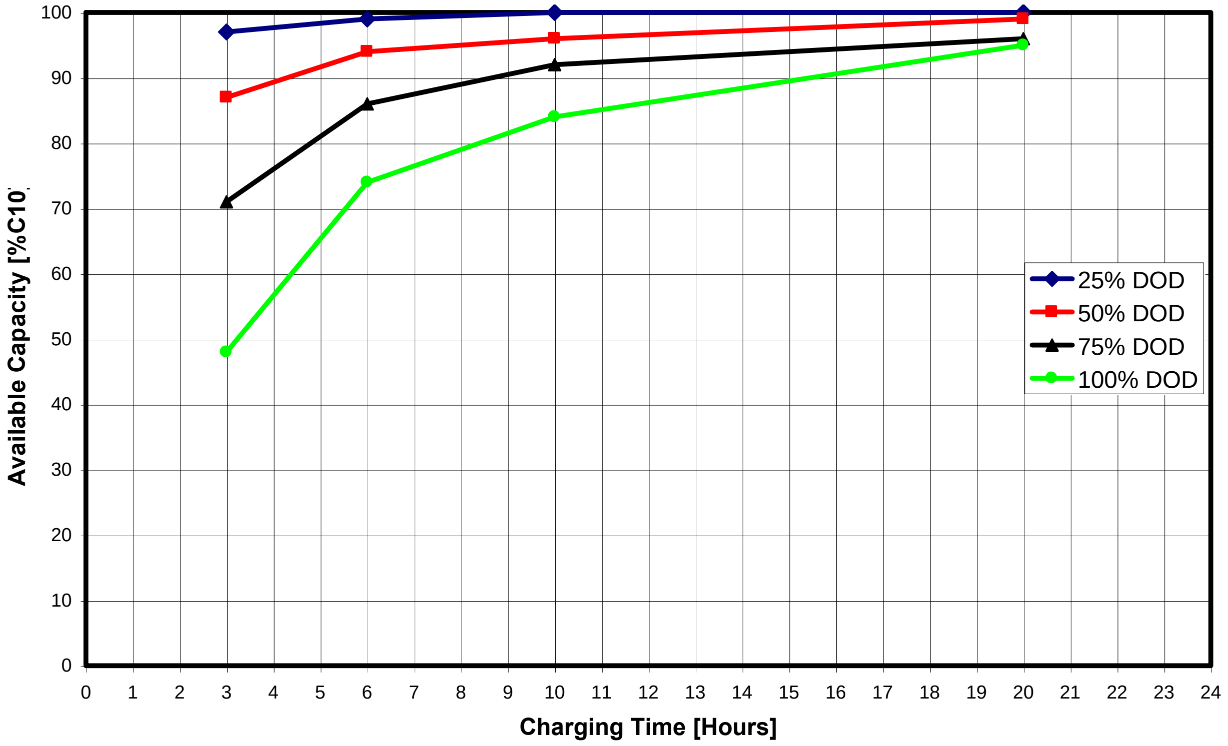


Fig. 27: Available Capacity versus Charging Time at 2.30 Vpc, Charging Current 2 • I_{10}, DOD = Depth of Discharge

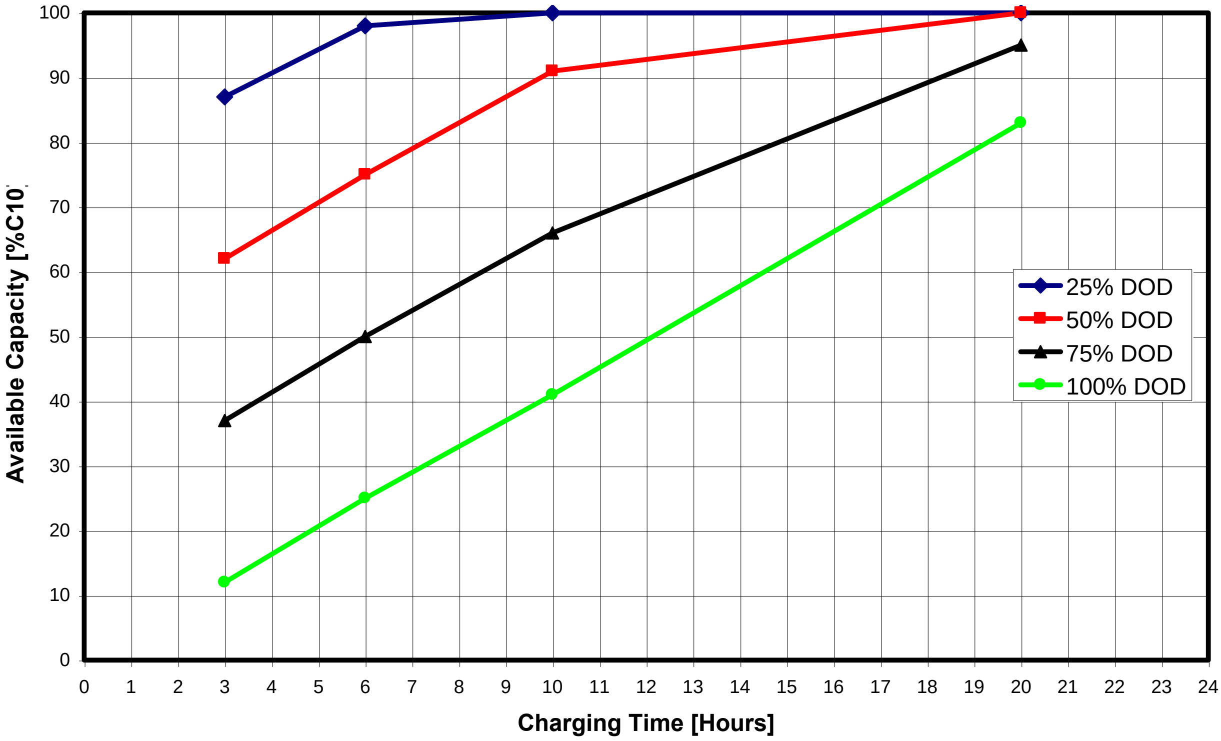


Fig. 28: Available Capacity versus Charging Time at 2.40 Vpc, Charging Current 0.5 • I_{10}, DOD = Depth of Discharge

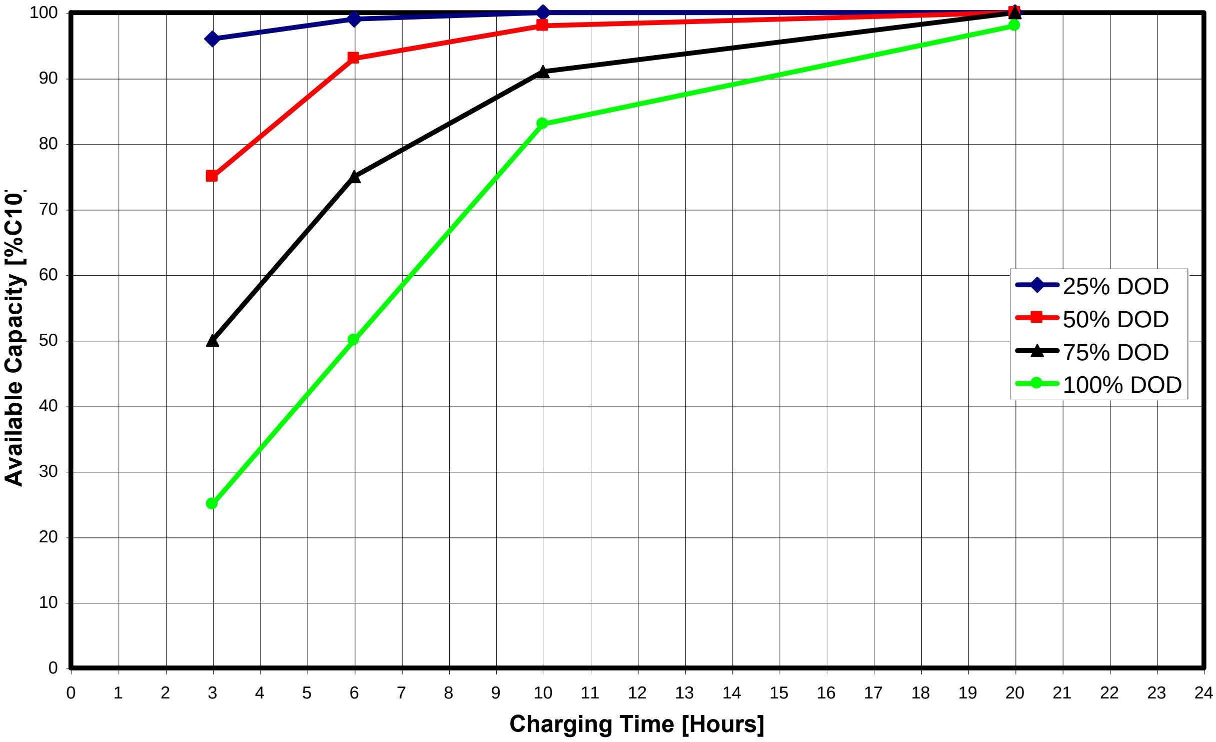


Fig. 29 (same as fig. 8 in chapter 6.4): Available Capacity vs. Charging Time at 2.40 Vpc, Charging Current 1 • I_{10}, DOD = Depth of Discharge

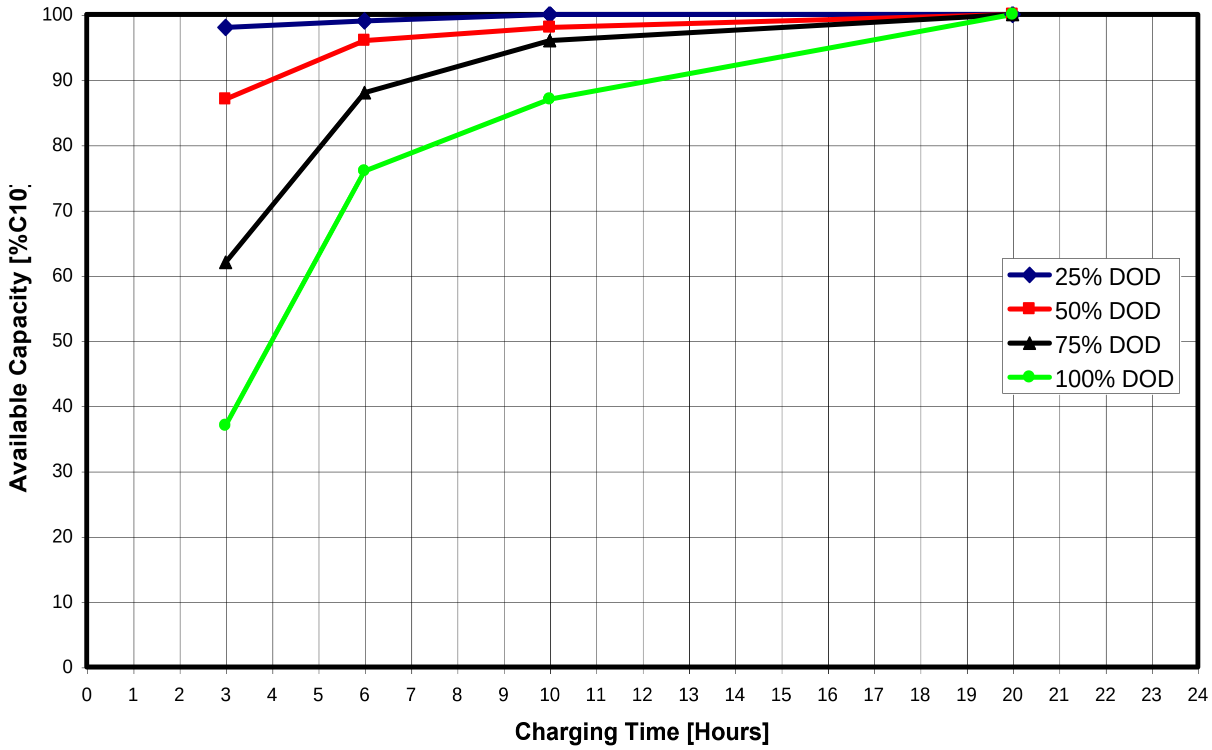


Fig. 30: Available Capacity versus Charging Time at 2.40 Vpc, Charging Current 1.5 • I_{10}, DOD = Depth of Discharge

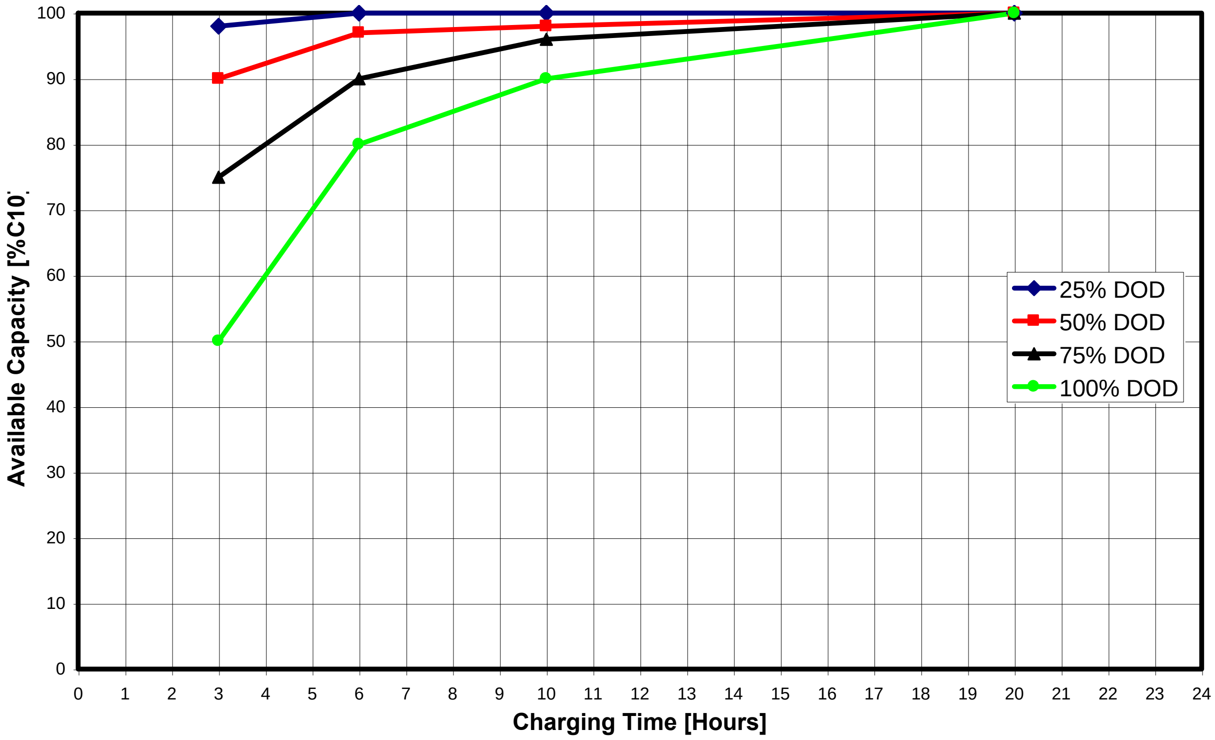


Fig. 31: Available Capacity versus Charging Time at 2.40 Vpc, Charging Current 2 • I_{10}, DOD = Depth of Discharge

Important Notice: The manufacturer of batteries “GNB Industrial Power” does not take over responsibility for any loyalties resulting from this paper or resulting from changes in the mentioned standards, neither for any different national standards which may exist and has to be followed by the installer, planner or architect.

EXIDE **Distributionscenter Berlin**
ELEKTRO.TEC GmbH
Eichborndamm 129-139
D-13403 Berlin

Tel.: 030/4111024
Fax: 030/4111025

www.elektrotec-berlin.de info@elektrotec-berlin.de

State: June 2015