Charging of
HOPPECKE OPzS solar.power battery
in Solar Applications

Preface:

This document provides hints for charging of HOPPECKE OPzS solar.power battery cells and blocs in solar applications.

Note: This document does not constitute general operating instructions. For safety precautions, installation, commissioning and operating instructions please refer to /1/ (Please contact your local HOPPECKE representative for further information).

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1. Settings for charging HOPPECKE OPzS solar.power batteries

1.1 General Charging Characteristic

The chart below (refer to Figure 1) demonstrates the OPzS solar.power recharge characteristic (IU-characteristic) after discharge with 50% DoD (Depth of Discharge).

Parameters (example):

- Charging voltage: 2,4 V/cell
- Charging current: 10 A / 100 Ah battery capacity (C10[1])
- Charging factor: 120%

The development of the state of charge (SoC) parameter is represented by the blue line; charging current by red line and charging voltage by the green line. Although 100% SoC are

[1] Available battery capacity depends on discharge current for lead acid batteries. This effect is caused by different material utilization. Please refer also to Annex III with a list of capacities for different discharge currents for OPzS solar.power product range.

reached after approx. 5 hours a total recharge time of ca. 12,5 hours is needed in order to reach the charging factor (here 120%).

Charging shall generally be performed according to IU or IUI_a characteristic (refer also to standard in /2/).

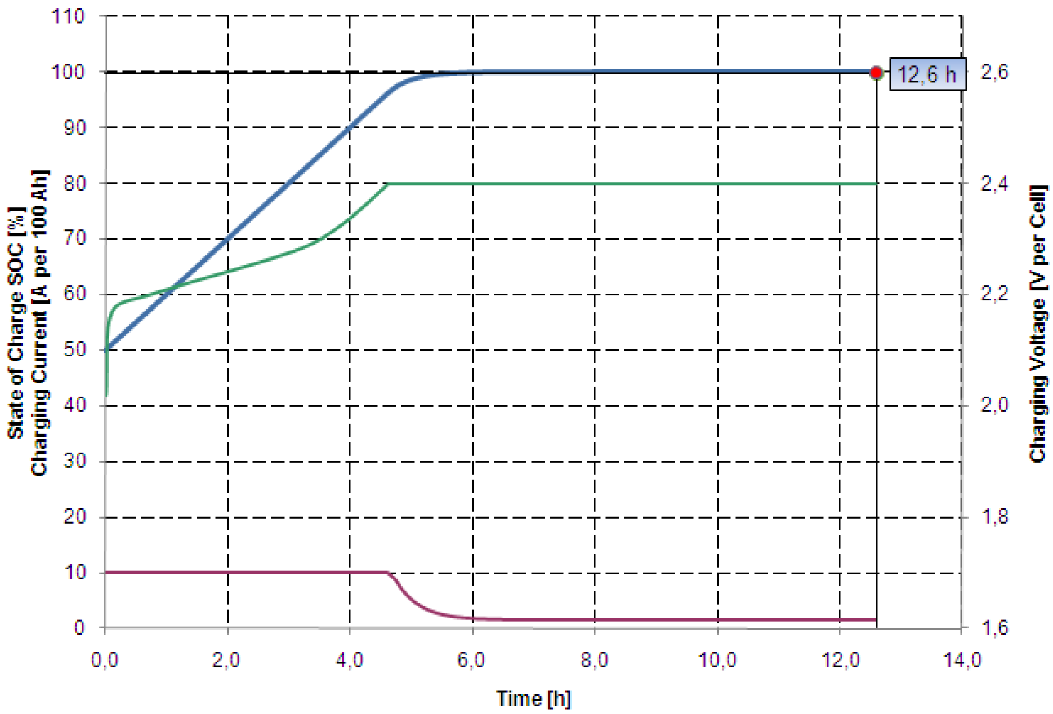

Figure 1: Charging characteristic of OPzS solar.power cell at 50% DoD

1.2 General hints for battery charging in solar or off-grid applications:

Charging procedure shall be compliant to IU- or IUI_a– characteristic (refer to example Figure 1 and to standard in /2/)). Recommended charging voltages for cyclical applications[2] are depicted in Figure 2.

1.3 Standard charge procedures:

IU - characteristic:
Used for regular recharge after every battery discharge. The charging procedure shall comply to IU-characteristic with 2.4 V/cell (refer to curve A in Figure 2). Note: Up to 2.4 V/C the charging current is theoretically not limited. However the recommended charging current is 5A to 20A[3]/100 Ah nominal battery capacity (C10).

IUI_a – characteristic:
Charge with IU-characteristic as described above. Keep the charging current at 5A/100Ah nominal battery capacity (C10) as soon as the current has dropped to this value during constant U-phase. During I_a phase the charging voltage ranges between 2.6 to 2.75 V/C

[2] Every battery discharge phase followed by a battery charge phase is referred to as a (battery) cycle.
[3] The higher the charge current (in the range of 5A to 20A/100Ah) the shorter the required charging time.

(refer to curve B in Figure 2). I_a phase should last either 2 or 4 hours (refer also to chapter 1.5 Charging procedure for cyclic applications).

If the battery is fully charged the charging voltage needs to be adjusted to normal float charge voltage for standby batteries as given in the HOPPECKE operating instructions (2.23V/cell at temperature between 10°C and 30°C; refer to /1/).

1.4 Equalizing Charge:

Equalizing charges are required after (deep) discharges with depth of discharge (DoD) of ≥ 80% and/or inadequate charges. They have to be executed as follows:

- Max. 2.4 V/Cell up to 72 hours (refer to curve A in Figure 2). Note: Up to 2.4 V/C the charging current is theoretically not limited. However a restriction of max. charging current to 20A/100 Ah nominal battery capacity (C10) is reasonable. In case of charging voltages above 2.4V/C the charging current needs to be restricted to 5A / 100 Ah battery capacity (C10). Resulting voltage range is 2.6 to 2.75 V/C (refer to curve B in Figure 2).
- The cell/bloc temperature must never exceed 55° C. If it does, stop charging or revert to float charge in order to allow temperature to fall. Avoid operating temperatures in excess of 45°C for long periods of time.
- The end of equalization charge is reached when the cell voltages and electrolyte densities do not increase during a period of 2 hours.

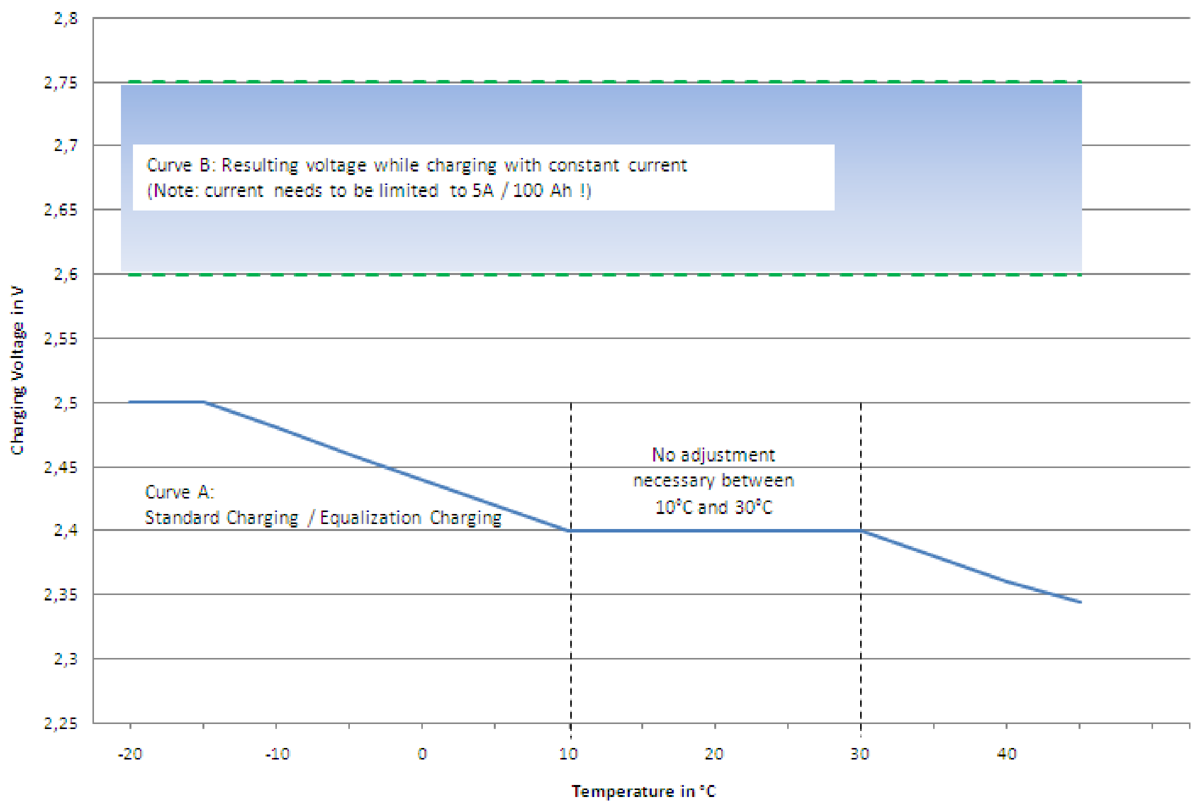

Figure 2 : Charging voltage as a function of temperature in solar cycling operation

Temperature dependent voltage adjustment as shown in Figure 2:

Operating temperature	Voltage adjustment per cell
< 10°C	+0.004 V/K (Voltage needs to be increased)
Between10°C to 30°C	No Adjustment
Between 30°C to 40°C	-0.004 V/K(Voltage needs to be decreased)
> 40°C	-0.003 V/K (Voltage needs to be decreased)

1.5 Charging procedure for cyclic applications

HOPPECKE recommends battery recharging according to the following guideline:

1. After every discharge, recharge battery to at least 90% state of charge according to these figures:

Depth of Discharge	2,4 V/C
15-50% DoD	Fig. II-1
55-100% DoD	Fig. II-2

2. After every 5 nominal throughputs, 10 cycles or 10 days (whatever occurs first), recharge battery with IUI_a characteristic. I_a phase with I = 5A/100Ah nominal battery capacity (C10) for two hours.

3. After every 10 nominal throughputs, 20 cycles or 20 days (whatever occurs first), recharge battery with IUI_a characteristic. I_a phase with I = 5A/100Ah nominal battery capacity (C10) for four hours.

The following figures depict examples for battery cycles:

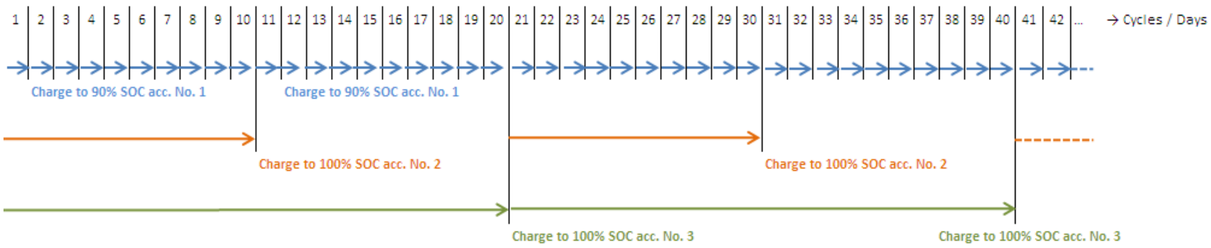

Figure 3: One battery cycle per day

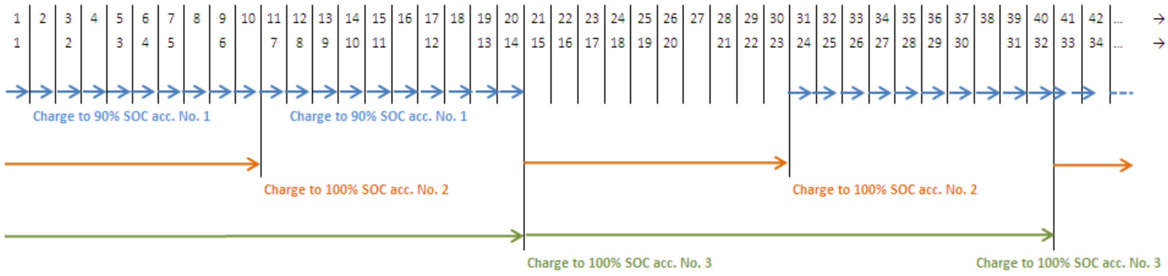

Figure 4: Phases with more than one battery cycle per day

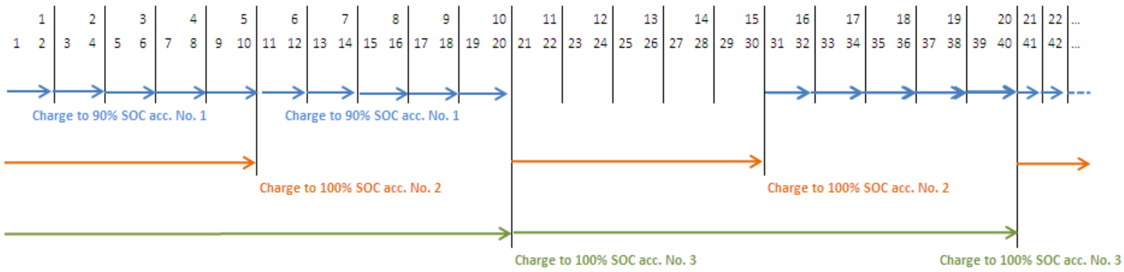

Figure 5: Battery cycles ranging longer than one day

1.6 Charging currents:

Recommended DC charging current range for boost and equalization mode is 5 to 20 A[4] / 100Ah nominal capacity (C10).

1.7 Alternating currents:

Depending on the charging equipment, its specification and its characteristics, superimposed alternating currents may contribute to battery charging current. Alternating currents and the corresponding reaction by the connected electrical loads may lead to an additional battery temperature increase, and – consequently - to a shortened battery service life as a result of stressed electrodes (micro cycling).
The alternating current must not exceed 5A (RMS) / 100 Ah nominal capacity.
In order to achieve the optimum service life for vented lead acid batteries on float charge, a maximum effective value of the alternating current of 2A per 100Ah battery capacity (C10) is recommended.

1.8 Water consumption:

Every lead acid battery decomposes certain amounts of water into hydrogen and oxygen gas. This effect rises with increasing amount of charge- / discharge cycles, charging voltage and battery temperature as well.

[4] The higher the charge current (in the range of 5A to 20A/100Ah) the shorter the required charging time.

2. Temperature influence on battery performance and lifetime

2.1 Temperature influence on battery capacity:

Battery capacity depends significantly on ambient temperature. Lead acid batteries loose capacity with decreasing temperature and vice versa, as shown in Figure 6. This should be considered when sizing the battery.

Temperature range for OPzS solar.power batteries:

Possible temperature range : -20℃ to 45℃
Recommend temperature range: 10℃ to 30℃

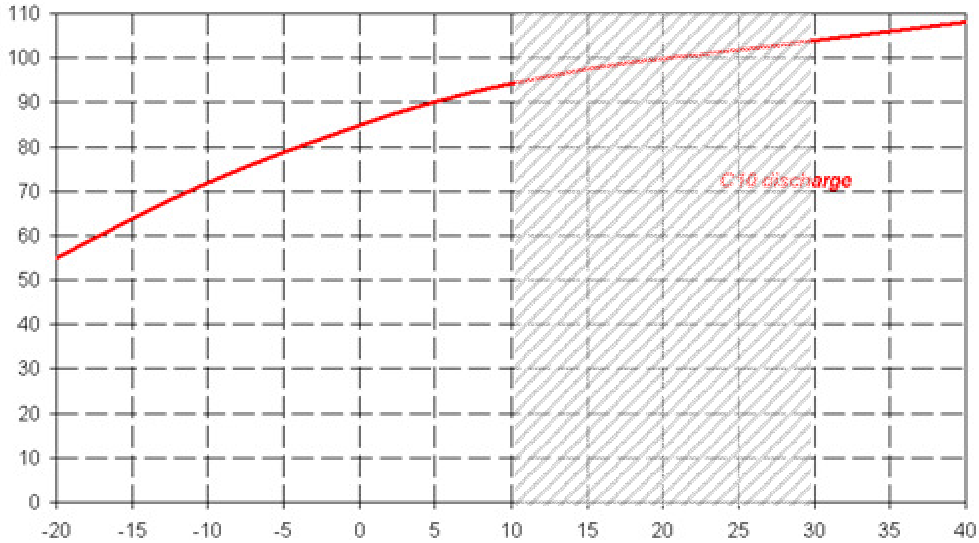

Figure 6: OPzS solar.power: Dependency of battery capacity on temperature

2.2 Temperature influence on battery lifetime:

As corrosion processes in lead acid batteries are significantly depending on battery temperature, the battery design lifetime is directly related to the ambient temperature.
As rule of thumb it can be stated that the speed of corrosion doubles per 10 K increase (rule by Arrhenius). Thus battery service life will be halved in case the temperature rises by 10 K.
The following graph (refer to Figure 7) shows this relationship. The diagram depicts operation in float charge mode. Additionally, the cycling lifetime has to be taken into account.

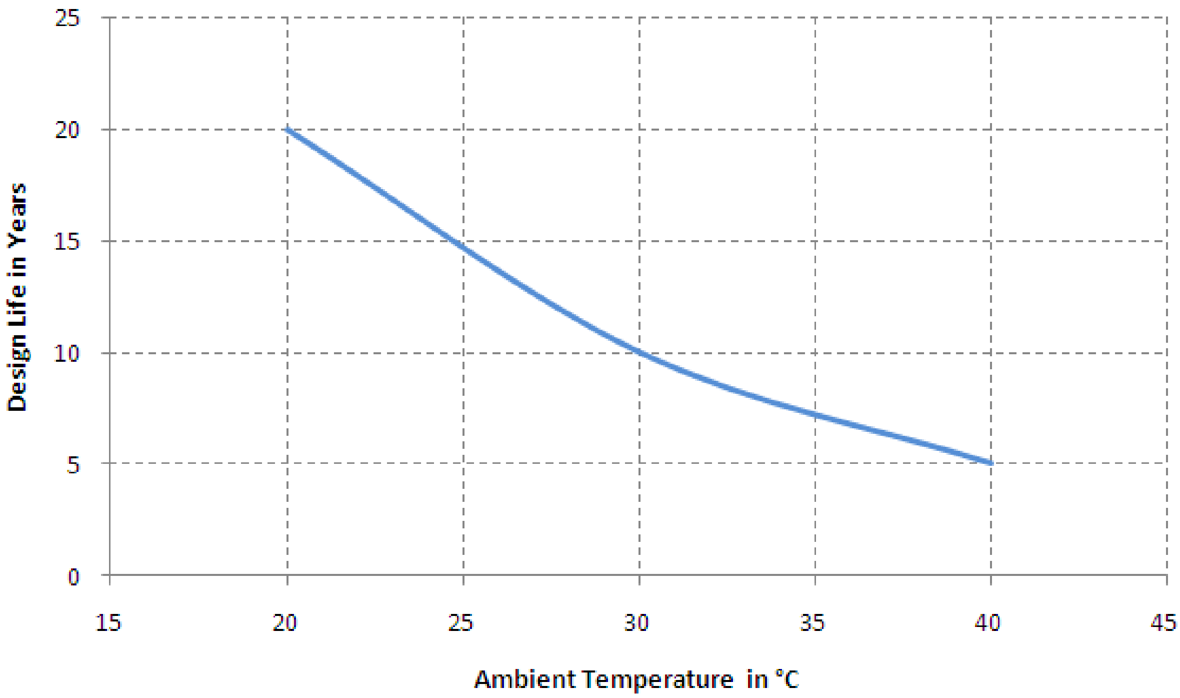

Figure 7: Design life of OPzS solar.power cell as a function of ambient temperature (standby application in float charge operation with 2.23V/cell)

3. Influence of cycling on battery behavior

3.1. Cycle life time depending on depth of discharge

Cycle lifetime is defined as number of discharging and charging cycles until the actual remaining battery capacity drops below 80% of the nominal capacity (C10). The cycle lifetime of a lead acid battery is directly depending on the regular depth of discharge (DoD) during these cycles.
Depending on different types of batteries and the design of the plates and electrodes, the cycle lifetime may vary significantly.
The following chart (Figure 8) shows the cycling behavior of a HOPPECKE OPzS solar.power under ideal operating conditions. The cycle life refers to one discharge per day. Cycle life cannot exceed stated service life under float charge conditions.

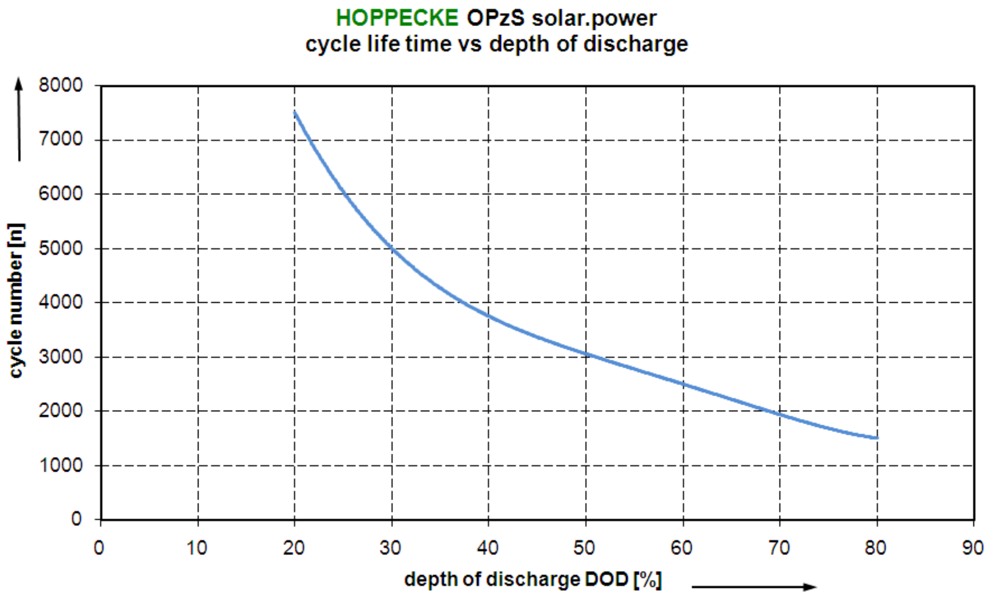

Figure 8 : Cycle lifetime of OPzS solar.power as a function of DoD (at 20℃)

3.2. Cycle life time depending on ambient temperature

Since design life mainly depends on temperature, the cycle lifetime is affected by temperature as well. Figure 9 depicts this relation for a regular battery depth of discharge of 80%.

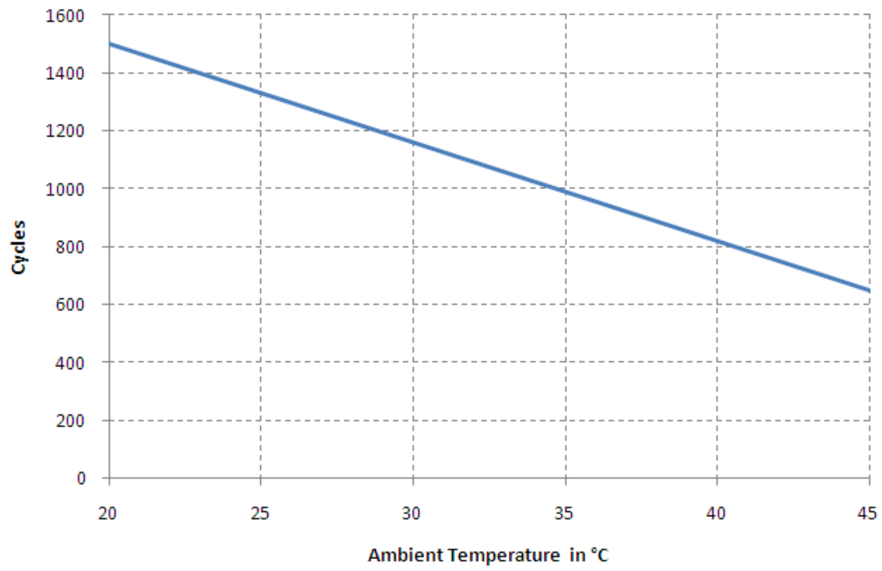

Figure 9: Cycle lifetime of OPzS solar.power as a function of ambient temperature

The following figure (refer to
Figure 10) depicts dependency of cycle life on depth of discharge and temperature.

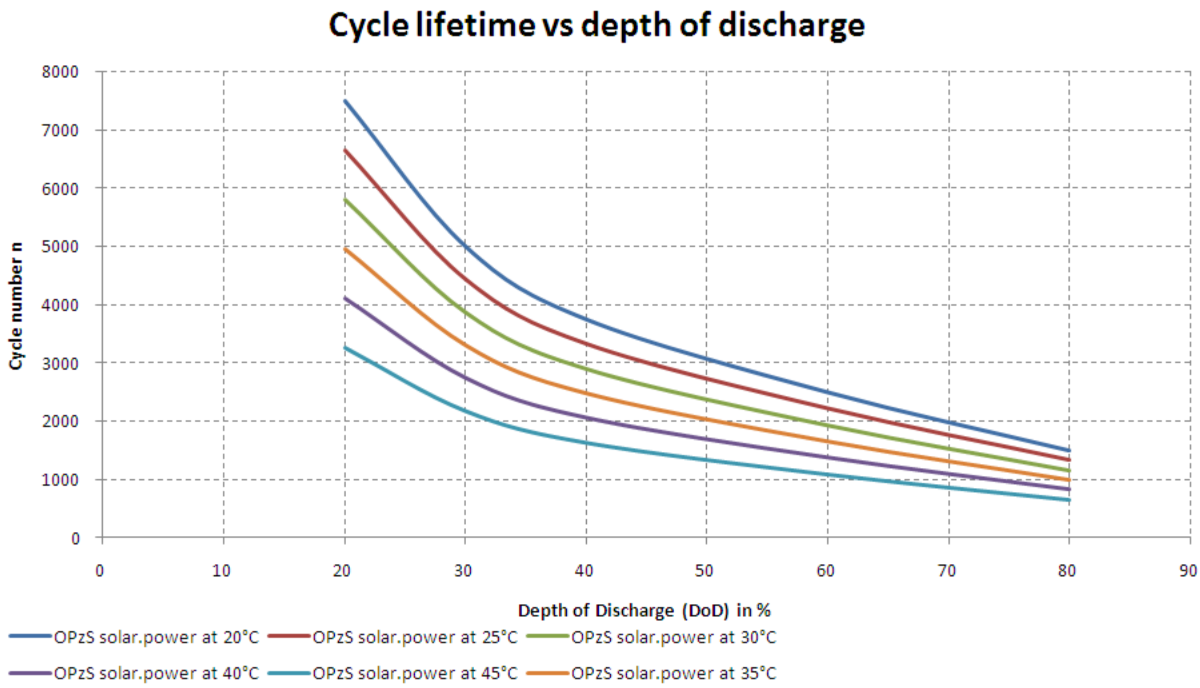

Figure 10: Cycle lifetime of OPzS solar power depending on DoD and temperature

3.3. Electrolyte freezing point depending on depth of discharge (DoD)

The freezing point of the electrolyte (sulphuric acid) rises with increasing depth of discharge. In case the battery is exposed to cold ambient temperatures (< -5°C) the maximum depth of discharge has to be decreased in order to avoid electrolyte freezing and potential damages of the cell jar. Figure 11 shows an example for this relation. Example: If depth of discharge is below 60% the operating temperature must not be below -18.4 °C.

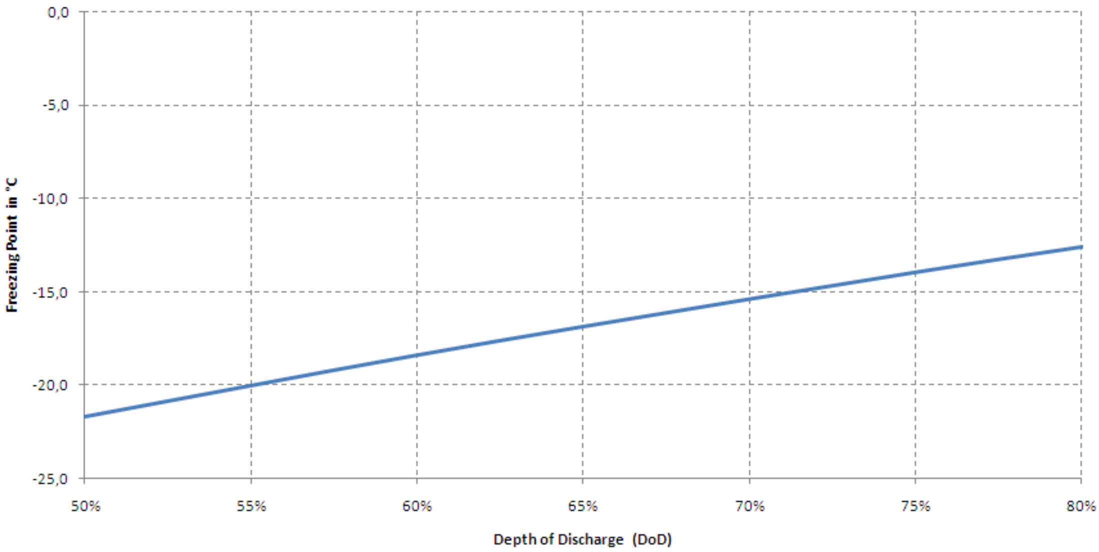

Figure 11: Electrolyte freezing point as a function of depth of discharge (DoD)

4. Remarks to warranty management

Above mentioned information about battery performance and lifetime, particularly concerning the charging procedure and the influence of temperature and cycling, affect terms of warranty as well.
In case of a warranty claim the customer / battery operator needs to prove the compliance of above mentioned parameters with the allowed / recommended limits. Corresponding measurement logs have to be sent to the battery manufacturer. These protocols shall clearly demonstrate that the lifetime of the affected battery has not been shortened by the application and associated parameters.
The expected service life mentioned by the battery manufacturer is valid for operation under optimal conditions only. Therefore, it is not possible to solely derive warranty claims from information on the expected service life provided by the manufacturer.

For special demanding operational conditions as well as for solar and off-grid applications the expected battery service lifetime is heavily influenced by above mentioned operational conditions. In order to decide whether a battery failure was caused by manufacturing defects or operational conditions, above mentioned parameters need to be monitored and registered on a regular basis. These data have to be forwarded to the manufacturer for further analysis.

HOPPECKE recommends the usage of a battery monitoring system for monitoring and logging of critical data. Please contact your local HOPPECKE representative for information on HOPPECKE battery monitoring equipment and accessories.

Annex I: Reference

/1/ "Installation, commissioning and operating instructions for vented stationary lead-acid batteries", Copyright HOPPECKE Batterien GmbH & Co. KG, Mar 2009

/2/ DIN 41773-1:1979-02: Static power convertors; semiconductor rectifier equipment with IU-characteristics for charging of lead-acid batteries, guidelines, 1979

Annex II: Glossary

DOD	Depth of discharge
I/U-Charge	Charging Procedure with constant current phase followed by a constant voltage charge.
IUI_a-Charge	Charging Procedure with constant current phase followed by a constant voltage phase and a constant current phase at the end.
Nominal throughput	A total discharge of C10 capacity is defined as one nominal throughput. The discharged capacity can also be interrupted by a charging phase.
SOC	State of Charge

Annex III: Capacities of OPzS solar.power product range

OPzS solar.power (single cell):

Type	C_{100}/1.85 V Ah	C_{50}/1.85 V Ah	C_{24}/1.83 V Ah	C_{10}/1.80 V Ah	C_5/1.77 V Ah
4 OPzS solar.power 280	280.0	265.0	244.8	213.0	181.5
5 OPzS solar.power 350	350.0	330.0	307.2	266.0	227.0
6 OPzS solar.power 420	420.0	395.0	369.6	320.0	272.5
5 OPzS solar.power 520	520.0	490.0	453.6	390.0	345.0
6 OPzS solar.power 620	620.0	585.0	542.4	468.0	414.0
7 OPzS solar.power 730	730.0	685.0	633.6	546.0	483.0
6 OPzS solar.power 910	910.0	860.0	796.8	686.0	590.0
8 OPzS solar.power 1220	1220.0	1145.0	1063.2	915.0	790.0
10 OPzS solar.power 1520	1520.0	1425.0	1324.8	1140.0	985.0
12 OPzS solar.power 1820	1820.0	1715.0	1591.2	1370.0	1185.0
12 OPzS solar.power 2170	2170.0	2010.0	1843.2	1610.0	1400.0
16 OPzS solar.power 2900	2900.0	2685.0	2472.0	2150.0	1865.0
20 OPzS solar.power 3610	3610.0	3350.0	3072.0	2680.0	2330.0
24 OPzS solar.power 4340	4340.0	4020.0	3696.0	3220.0	2795.0

OPzS bloc solar.power (bloc type):

Type	C_{100}/1.85 V Ah	C_{50}/1.85 V Ah	C_{24}/1.83 V Ah	C_{10}/1.80 V Ah	C_5/1.77 V Ah
12V 1 OPzS bloc solar.power 70	70.0	65.0	60.0	50.0	44.0
12V 2 OPzS bloc solar.power 130	130.0	130.0	120.0	101.0	88.0
12V 3 OPzS bloc solar.power 200	200.0	190.0	180.0	151.0	132.0
6V 4 OPzS bloc solar.power 270	270.0	255.0	240.0	202.0	176.0
6V 5 OPzS bloc solar.power 330	330.0	320.0	297.6	252.0	220.0
6V 6 OPzS bloc solar.power 400	400.0	380.0	357.6	302.0	263.5

C100, C50, C24,C10, C5 = Capacity at 100h, 50h, 24h, 10h and 5h discharge

Annex IV: Recharge-time diagrams

The following diagrams depict approximately necessary recharge times with IU-characteristic as a result of the maximum possible charging current and the actual depth of discharge (DoD) at begin of the recharge phase.

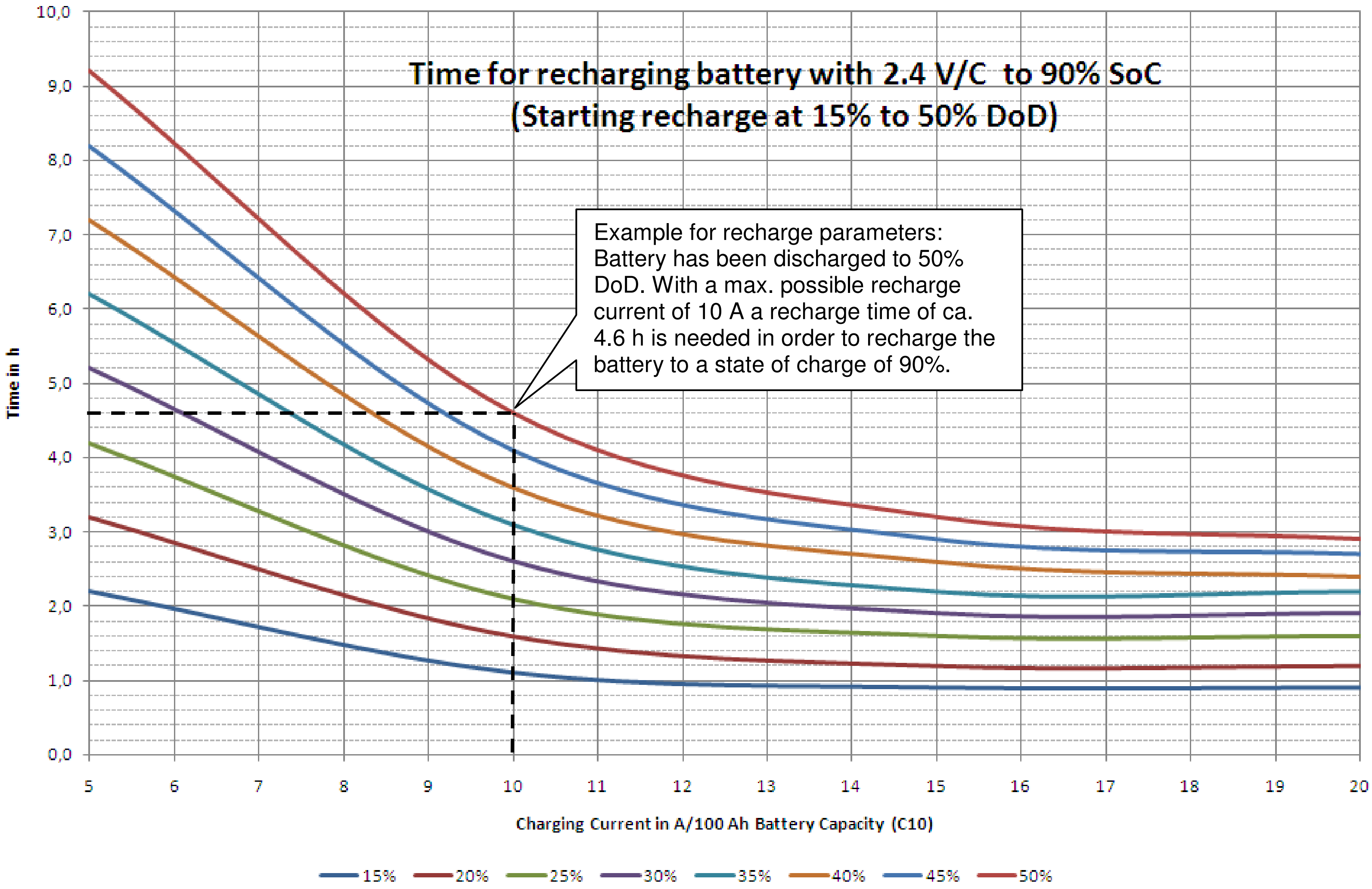

Fig-II 1: Recharge after every discharge

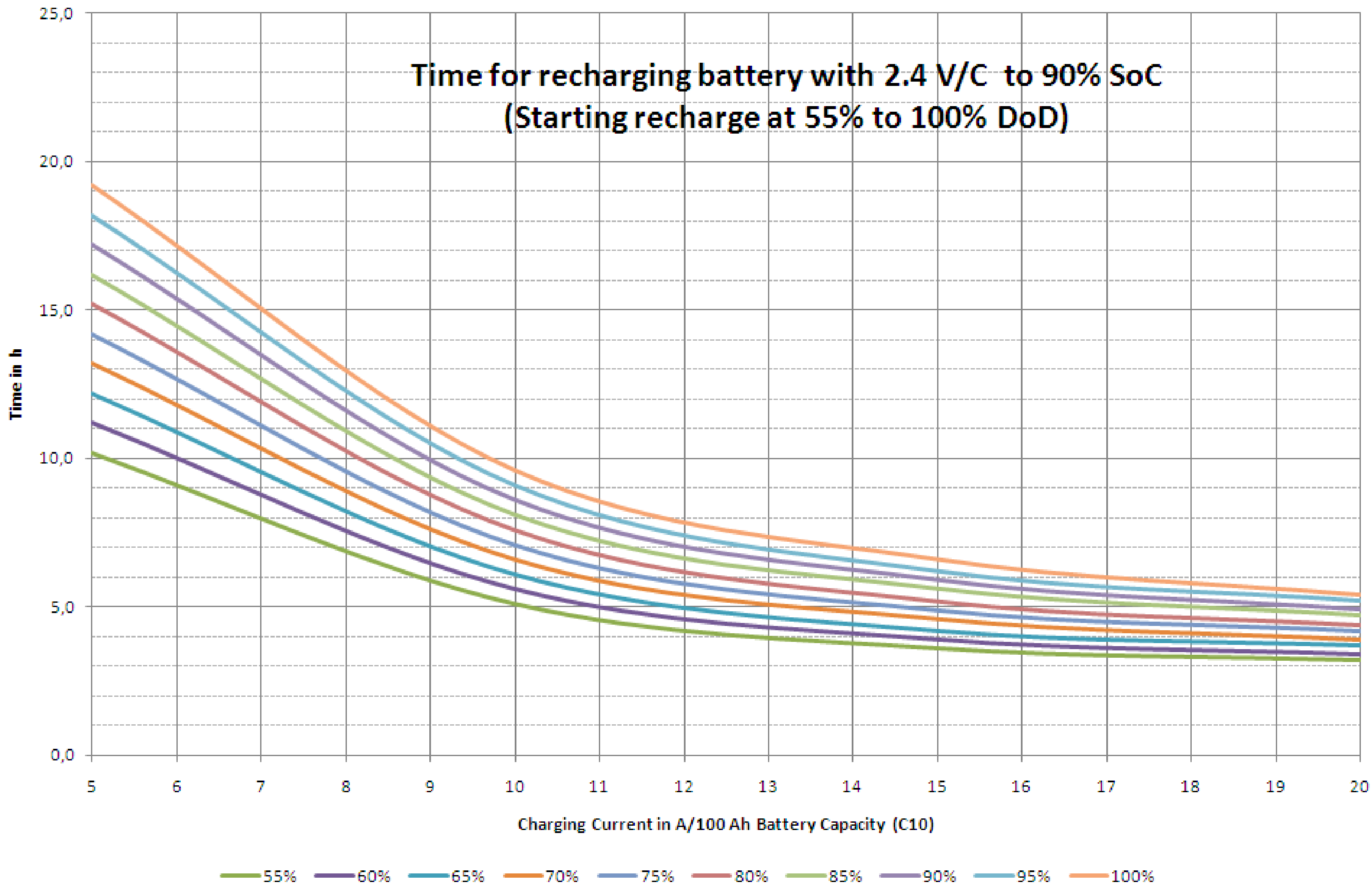

Fig-II 2: Recharge after every discharge