Charging of
HOPPECKE OPzV solar.power battery
in Solar Applications

Preface:

This document provides hints for charging of HOPPECKE OPzV 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 OPzV solar.power batteries

1.1 General Charging Characteristic

The chart below (refer to Figure 1) demonstrates the OPzV solar.power recharge characteristic (IU-characteristic) after a discharge of 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: 1.1 (110%)

[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 OPzV solar.power product range.

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The development of the state of charge (SoC) parameter is represented by the blue line; charging current by the red line and charging voltage by the green line. Although 100% SoC are reached after approx. 7 hours a total recharge time of 10 to 11 hours is needed in order to reach the charging factor (here 110%).

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

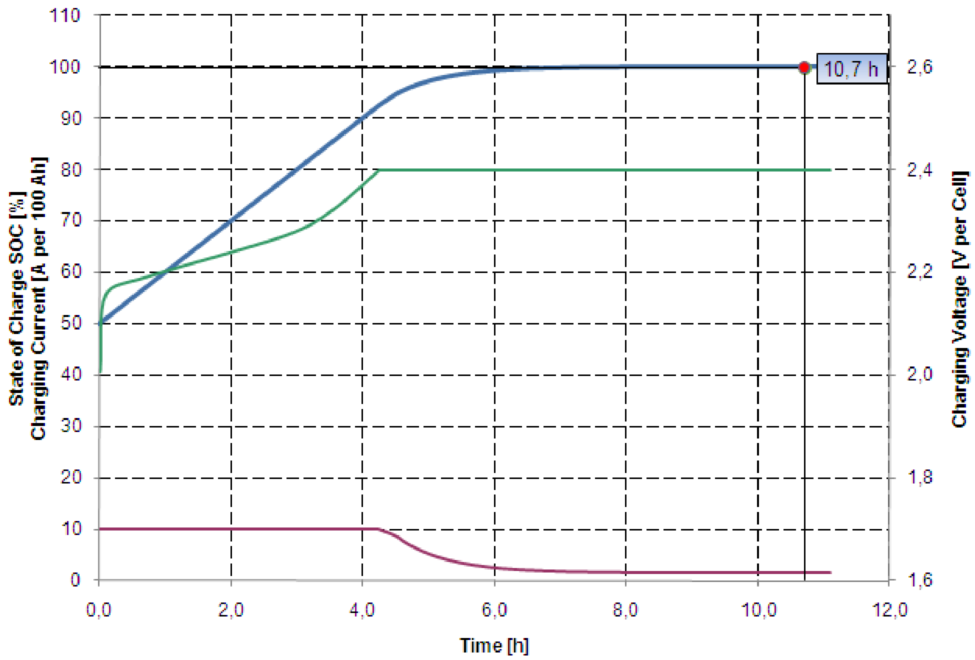

Figure 1: Charging characteristic of OPzV solar.power cell at 50% DoD

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
There are two variants which can be applied for regular recharge after every discharge:

1. Boost charge (charger equipped with two-stage controller):
   Charge with boost charge voltage (refer to curve C in Figure 2) for max. 2 hours per day. The charging voltage has to be reduced after max. 2h in boost voltage stage (refer to curve A in Figure 2).
   Charging current should range at 5A to 20A[3] per 100Ah battery capacity (C10).
   After the charging current has reached 1A/100Ah battery capacity (C10) the charging voltage needs to be adjusted to normal float charge voltage for standby batteries as given in the HOPPECKE operating instructions (2.25V/cell at temperature between

[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.

15°C and 35°C; refer to /1/).

2. Charger without voltage switching
   Charge with standard charge voltage (refer to curve B in Figure 2).
   Charging current should range at 5A to 20A[3] per 100Ah battery capacity (C10).
   After the charging current has reached 1A/100Ah battery capacity (C10) the charging voltage needs to be adjusted to normal float charge voltage for standby batteries as given in the HOPPECKE operating instructions (2.25V/cell at temperature between 15°C and 35°C; refer to /1/).

IUI_a – characteristic:
Charge with IU-characteristic as described above. Keep the charging current at 1 A/100 Ah 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 should not exceed 2.8 V/C. I_a phase should last either 2 or 4 hours (refer also to chapter 1.5 Charging procedure for cyclic applications).

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 48 hours (refer to curve A in Figure 2)
- Charging current shall not exceed 20 A/100 Ah of nominal battery capacity (C10).
- The cell/bloc temperature must never exceed 45° C. If it does, stop charging or revert to float charge in order to allow temperature to fall.
- The end of equalization charge is reached when the cell voltages do not change during a period of 2 hours.

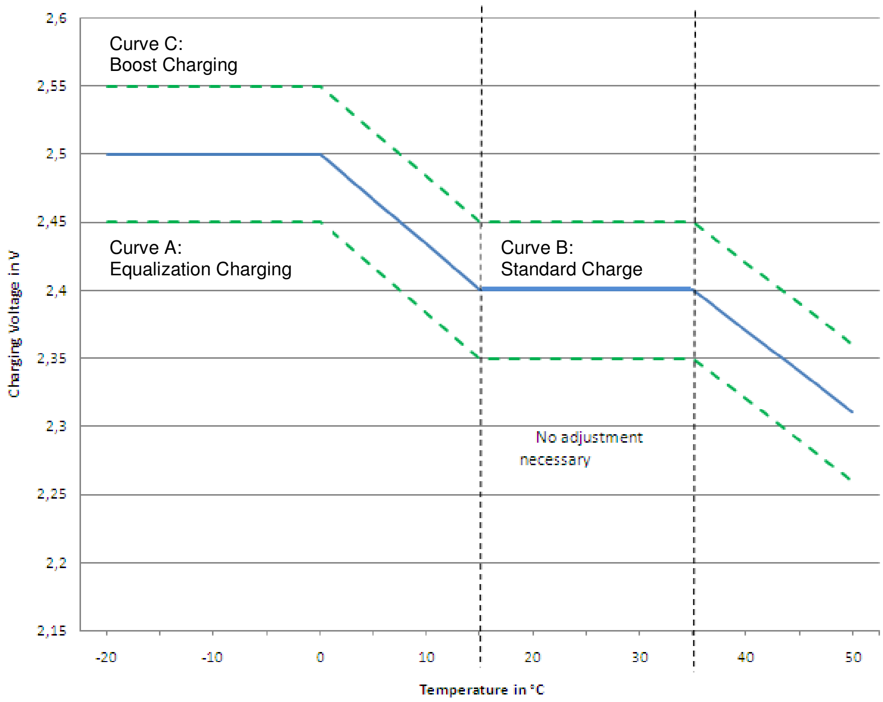

Figure 2 : charging voltage as a function of temperature in solar cycling operation

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 = 1A/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 = 1A/100Ah nominal battery capacity (C10) for four hours.

The following figures depict examples for battery cycles:

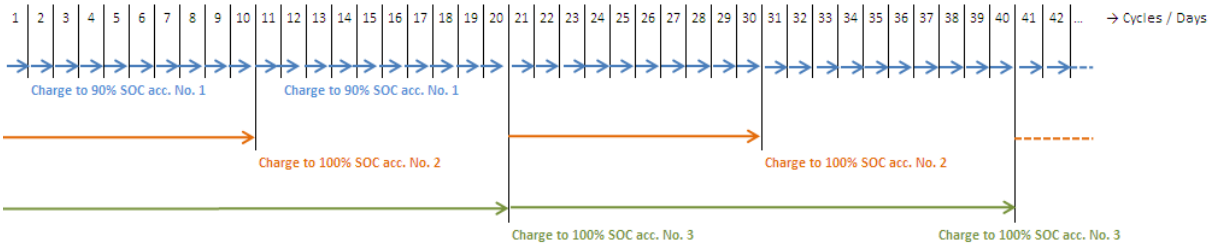

Figure 3: One battery cycle per day

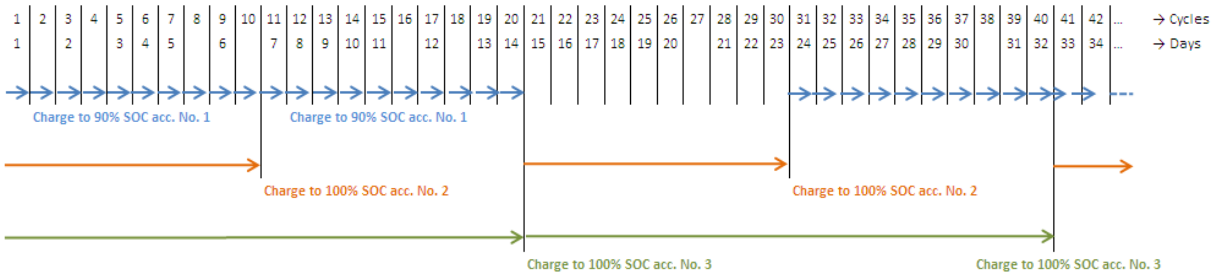

Figure 4: Phase with more than one battery cycle per day

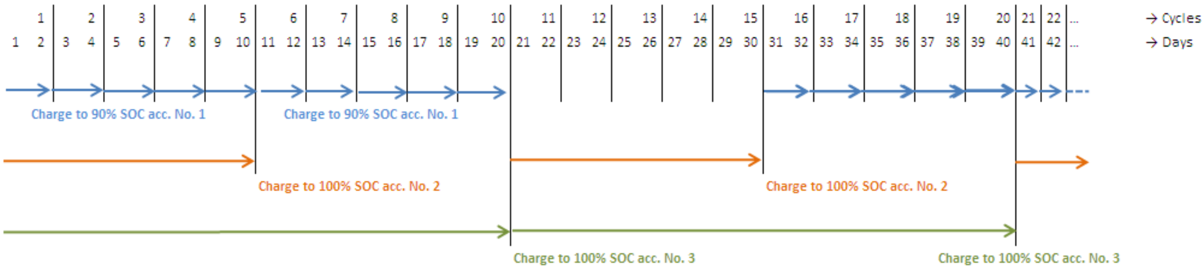

Figure 5: Battery cycles ranging longer than one day

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 1A (RMS) / 100 Ah nominal capacity.

[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 OPzV solar.power batteries:

Possible temperature range : -20℃ to 45℃
Recommend temperature range: 15℃ to 35℃

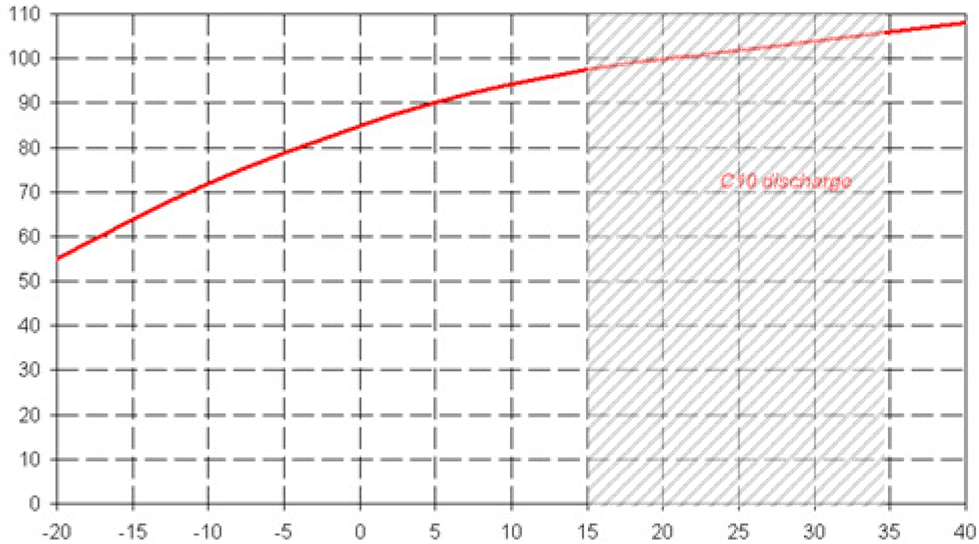

Figure 6: OPzV solar.power: Dependency of battery capacity on temperature

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 10K increase (rule by Arrhenius). Thus battery service life will be halved in case the temperature rises by 10K.
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.

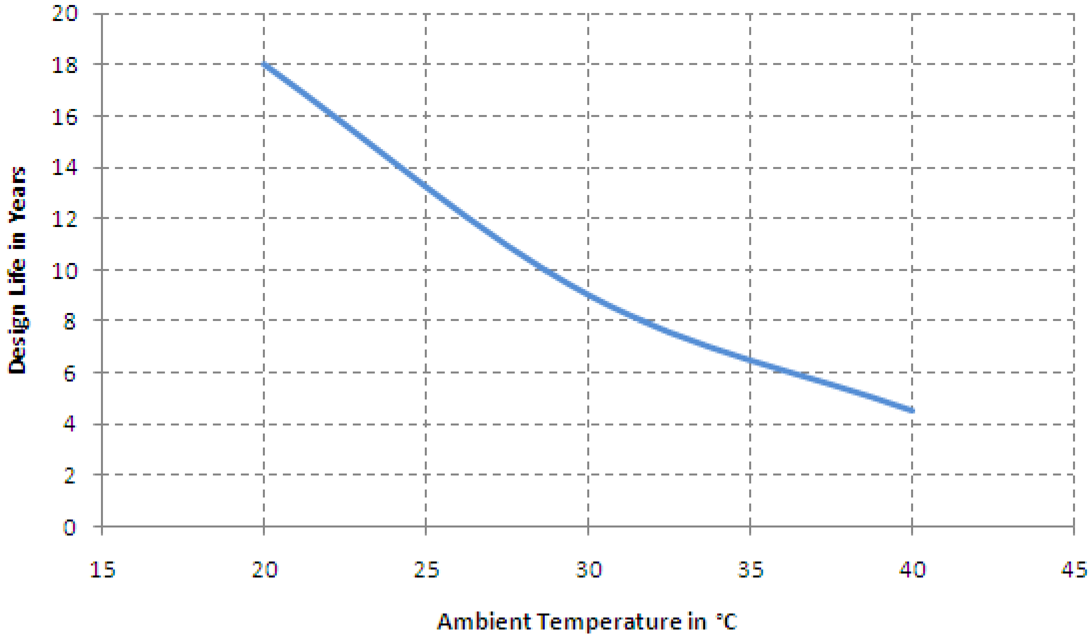

Figure 7: Design life of OPzV solar.power cell as a function of ambient temperature (standby application in float charge operation with 2.25V/cell)

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 (refer to Figure 8) shows the cycling behavior of a HOPPECKE OPzV 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.

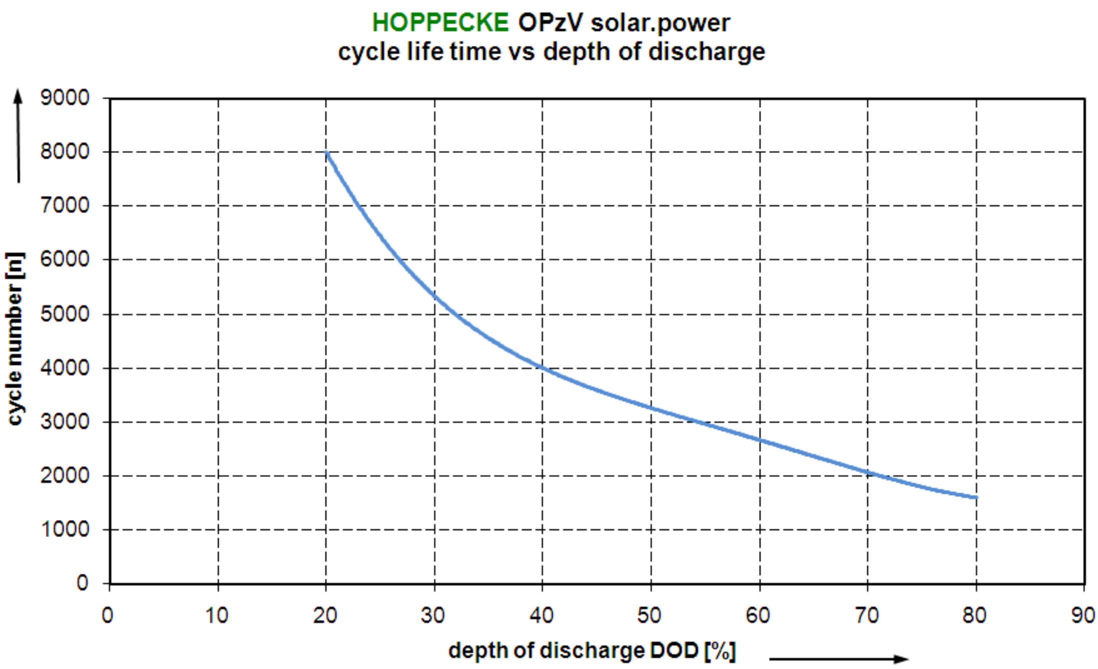

Figure 8 : Cycle lifetime of OPzV solar.power as a function of DoD (at 20°C)

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%.

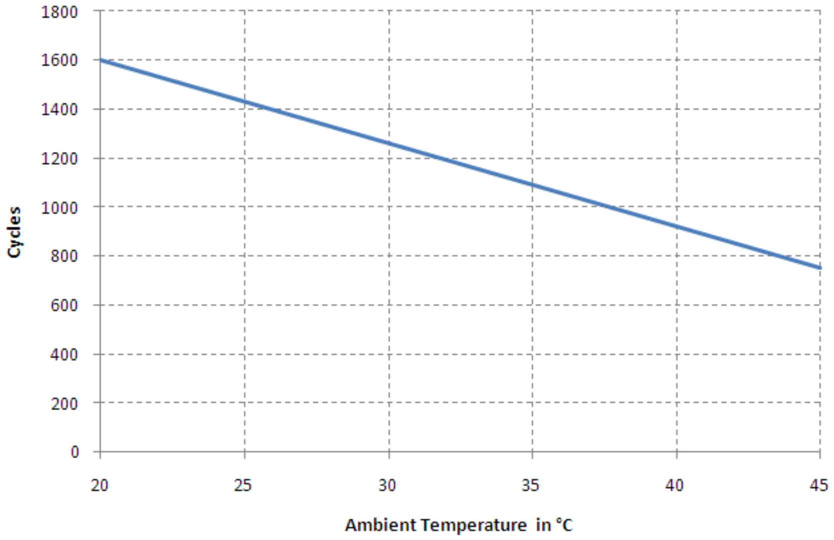

Figure 9: Cycle lifetime of OPzV solar.power as a function of ambient temperature

The following figure depicts dependency of cycle life on depth of discharge and temperature.

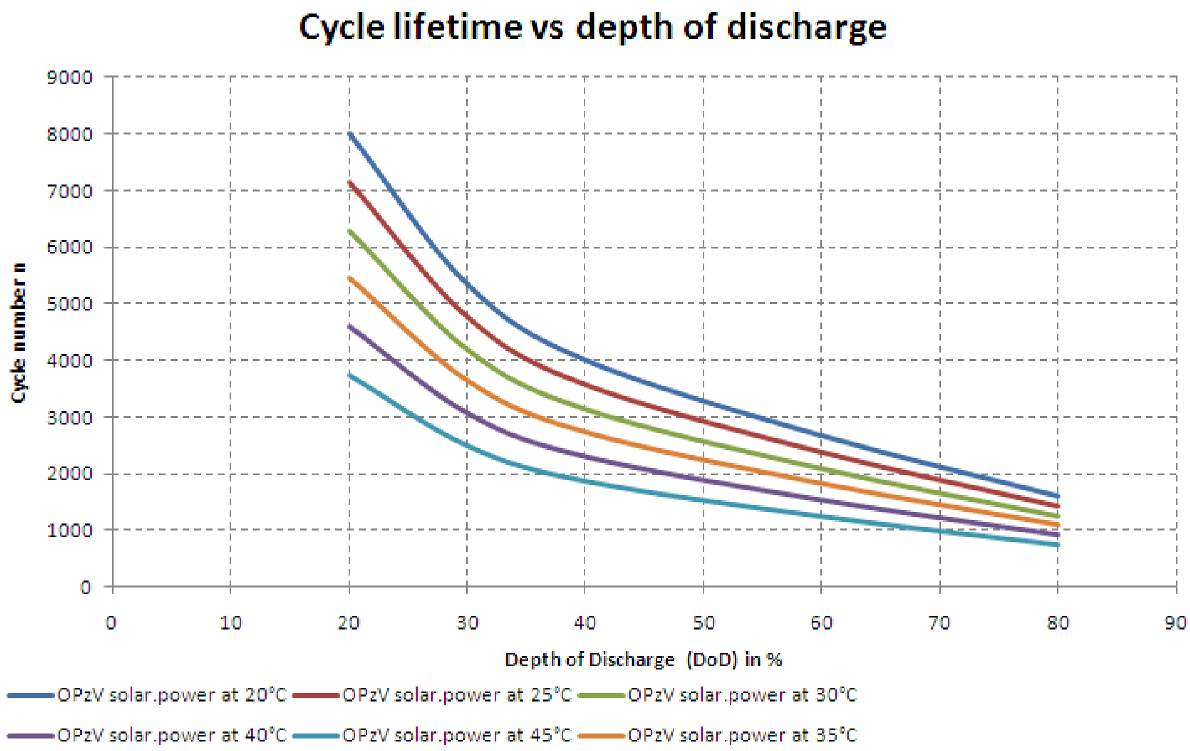

Figure 10: Cycle lifetime of OPzV solar power depending on DoD and temperature

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 (< 0℃) 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 -23.4 ℃.

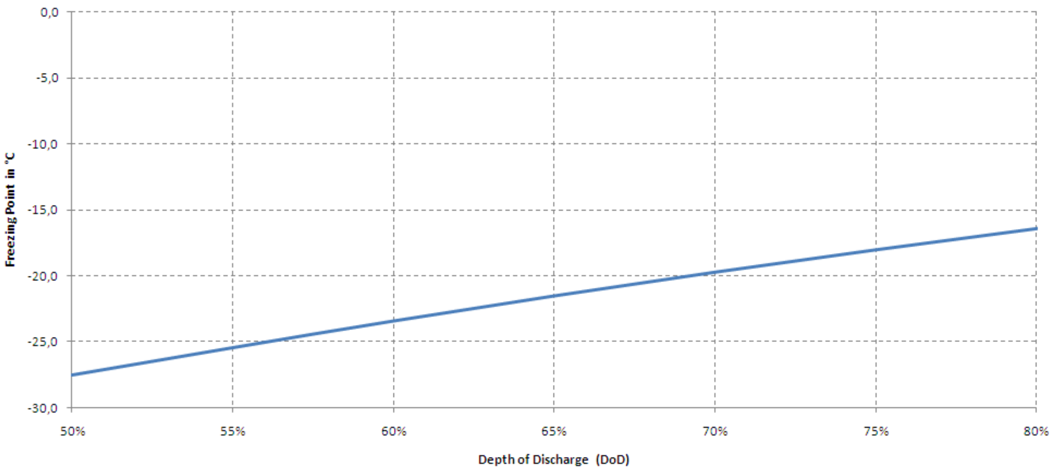

Figure 11: Electrolyte freezing point as a function of depth of discharge (DoD)

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 sealed 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
V/C	Volt per cell

Annex III: Capacities of OPzV solar.power product range

OPzV 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 OPzV solar.power 250	250.0	225.0	225.6	207.0	188.5
5 OPzV solar.power 310	310.0	285.0	278.4	259.0	235.5
6 OPzV solar.power 370	370.0	340.0	336.0	310.0	283.0
5 OPzV solar.power 420	440.0	440.0	436.8	391.0	347.0
6 OPzV solar.power 520	560.0	530.0	525.6	469.0	416.0
7 OPzV solar.power 620	660.0	620.0	612.0	548.0	484.5
6 OPzV solar.power 750	810.0	745.0	739.2	682.0	595.0
8 OPzV solar.power 1000	1080.0	995.0	981.6	910.0	795.0
10 OPzV solar.power 1250	1350.0	1245.0	1228.8	1140.0	990.0
12 OPzV solar.power 1500	1570.0	1490.0	1476.0	1370.0	1190.0
12 OPzV solar.power 1700	1720.0	1675.0	1658.4	1520.0	1275.0
16 OPzV solar.power 2300	2320.0	2235.0	2210.4	2030.0	1695.0
20 OPzV solar.power 2900	2930.0	2795.0	2760.0	2540.0	2125.0
24 OPzV solar.power 3500	3540.0	3350.0	3312.0	3050.0	2545.0

OPzV 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 OPzV bloc solar.power 70	70.0	55.0	55.2	48.0	42.5
12V 2 OPzV bloc solar.power 120	120.0	120.0	110.4	96.0	84.0
12V 3 OPzV bloc solar.power 180	180.0	175.0	165.6	144.0	126.5
6V 4 OPzV bloc solar.power 250	250.0	235.0	220.8	192.0	168.5
6V 5 OPzV bloc solar.power 300	300.0	295.0	276.0	240.0	210.5
6V 6 OPzV bloc solar.power 370	370.0	350.0	333.6	289.0	252.5

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.

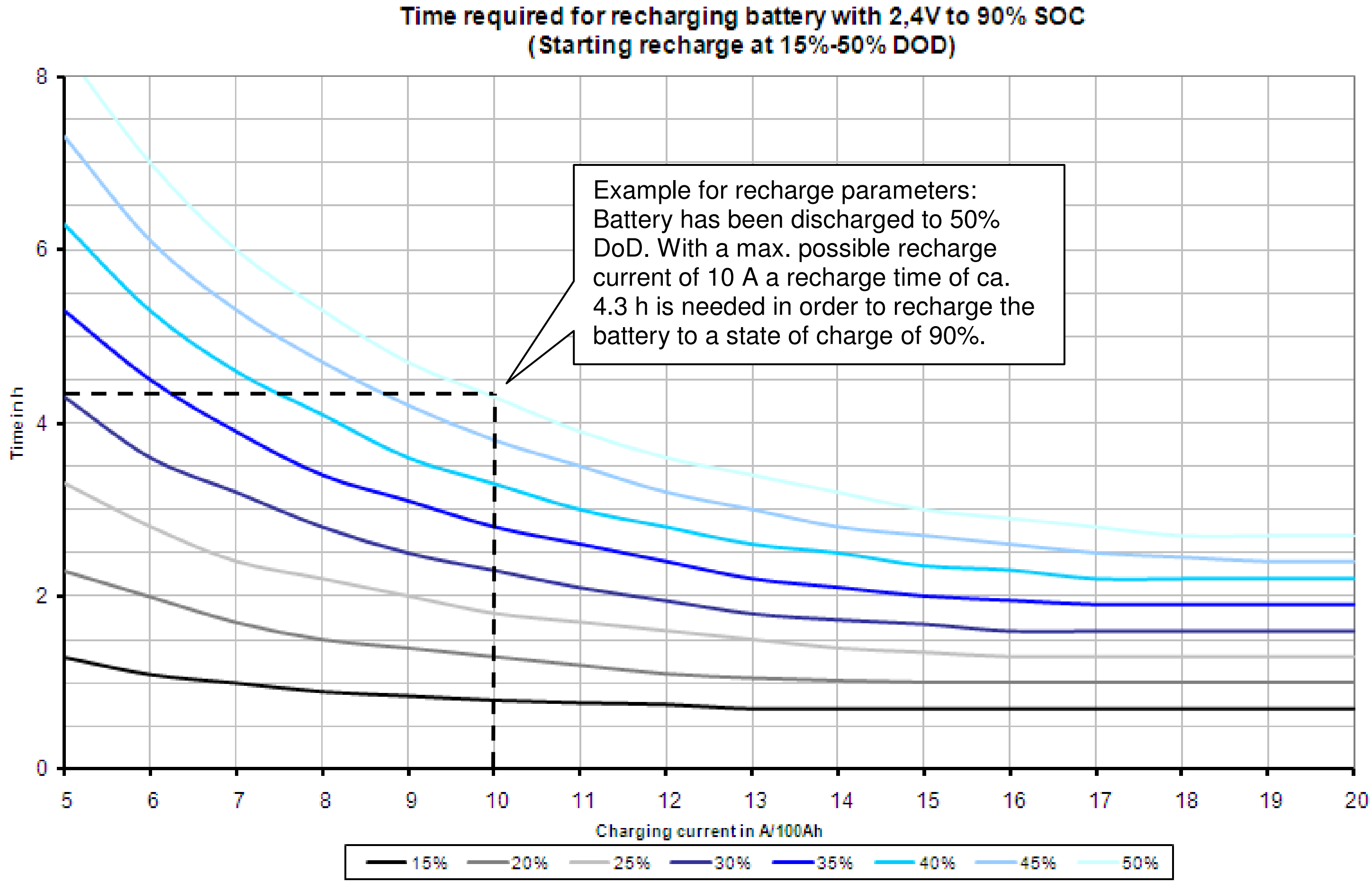

Fig-II 1: Recharge after every discharge

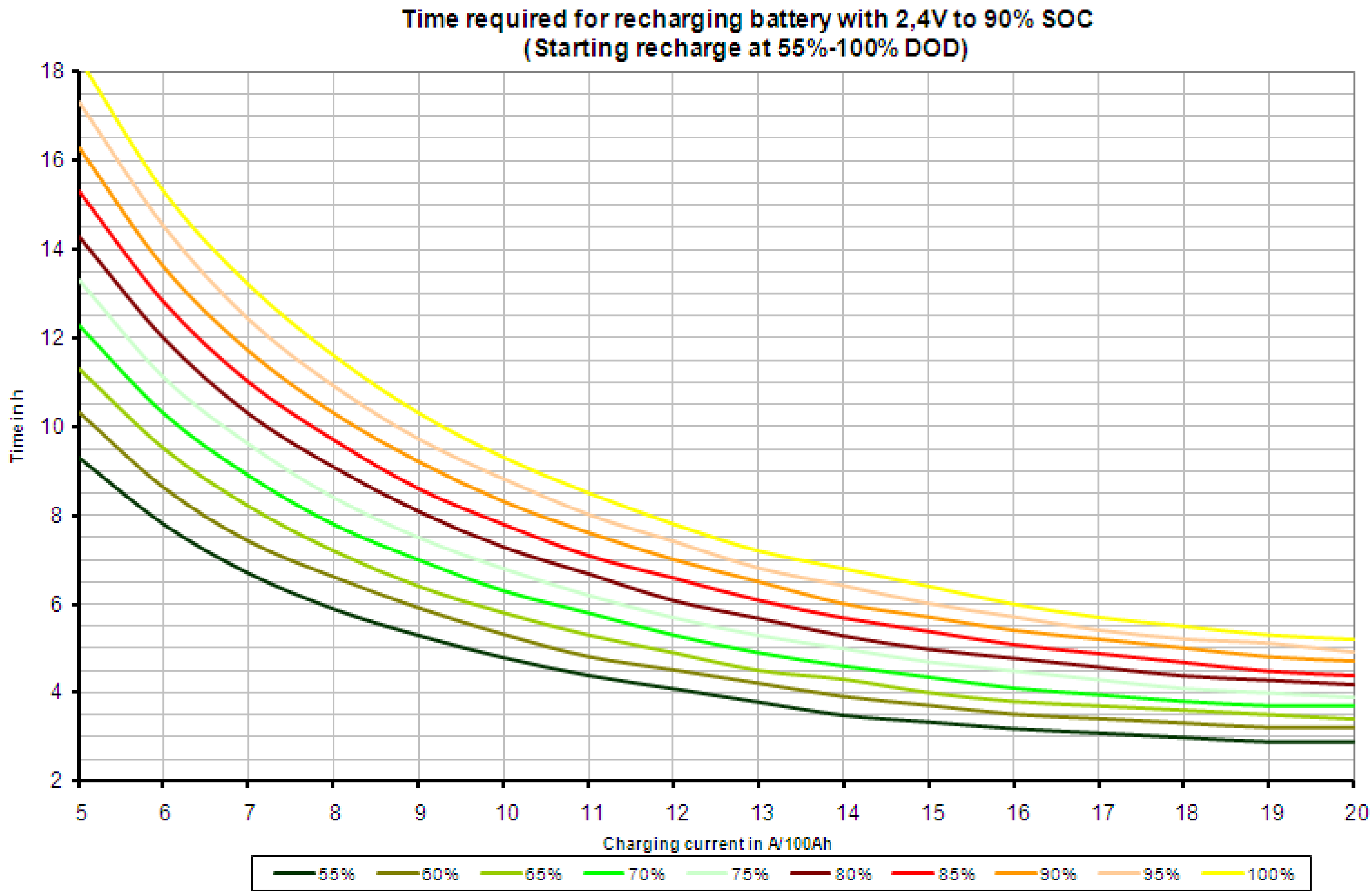

Fig-II 2: Recharge after every discharge