ZVEI: Batterien

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Requirements for battery discharge indicators for lead acid traction batteries

In order to achieve a high economic efficiency

The economic efficiency of a traction battery is primarily determined by its service life. Besides from an optimised application oriented matching of the battery system the service life is decisively influenced by its operating conditions and its maintenance.
High operating temperatures and deep discharges are main influence factors which are affecting the service life negatively and must be avoided therefore.
In order to avoid deep discharges, instead of the nominal capacity the operating capacity C_B, which is 80% of the nominal capacity C_N (100 % C_B = 80 % C_N), is important.
This is because in the normal discharge operation only the operating capacity must be discharged.
Discharge indicators have the function to protect the battery from deep discharges.

This leaflet contains explanations concerning the discharge characteristic of traction batteries, the issue of deep discharge, as well as general requirements for discharge indicators.

1. Why should discharge indicators be used ?

Discharge indicators serve the protection of batteries from deep discharges. Deep discharges are detrimental for the battery and reduce the service life (please see ZVEI leaflet “Considerations on traction batteries” and the battery manual).

Discharge indicators can only protect the battery, if they are adapted to the battery technology and the real operating conditions and are adjusted correctly.

2. What happens in case of a deep discharge ?

A deep discharge is a discharge of more than 80 % of the nominal capacity (C5). For PzS batteries (low maintenance, flooded design) this is equivalent to an electrolyte density of less than 1.13 kg/l (30°C), respectively an open circuit voltage of less than 1.97 V/cell.

Deep discharges result in:

- exceedingly high stress of the active masses because of the volume increase (up to a factor of three) due to the lead sulphate formation
- increased corrosion of the electrodes because of low acid density and higher temperatures
- possibly a refused start respectively an immediate abortion of the charge by the charger
- significant prolongation of the charging time, which bears the danger of insufficient charging
- in extreme cases to the reversal of single cells

Repeated deep discharges result in:

- irreversible hardening of the active masses in the electrodes through sulphatation and premature capacity loss.
- extreme sludging of the positive active mass and by this to short circuits.

Each deep discharge requires, because of the inhibited charge acceptance and the danger of insufficient charging, an equalising charge after finishing the normal charge.

Basically any kind of deep discharge results in a significant shortening of the service life.
A 100 % depth of discharge will reduce the service life by one

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third compared to the discharge of the operational capacity.

3. Methods to determine the depth of discharge (DOD)

The depth of discharge (DOD) can be determined with the help of the following methods:

- Measurement of the open circuit voltage
- Measurement of the discharge voltage
- Measurement of the electrolyte density
- Integration of the discharge current over the discharge time, respectively the discharged Amperehours

In today´s practice mainly discharge indicators are used, which measure and evaluate the battery discharge voltage and /or battery open circuit voltage (see point 4.)

Increasingly discharge indicators for BATTERIEBUS enabled battery controller are used, which evaluate voltage, current and temperature (see point 5.).

For the manual control of the discharge indicator setting the following measurements are possible:

- Measurement of the electrolyte density under consideration of the electrolyte temperature [Correction factor -0.0007 kg/l/K.
  Example: the value 1.29 kg/l at 30°C is equivalent to the value 1.28 kg/l at 45°C]
- Measurement of the open circuit voltage.

Here applies:

open circuit voltage per cell
U_o =
electrolyte density + 0.84
measured after at minimum of 2 h rest period (PzS and GiS)

4. How does the battery voltage relate to the depth of discharge (DOD)

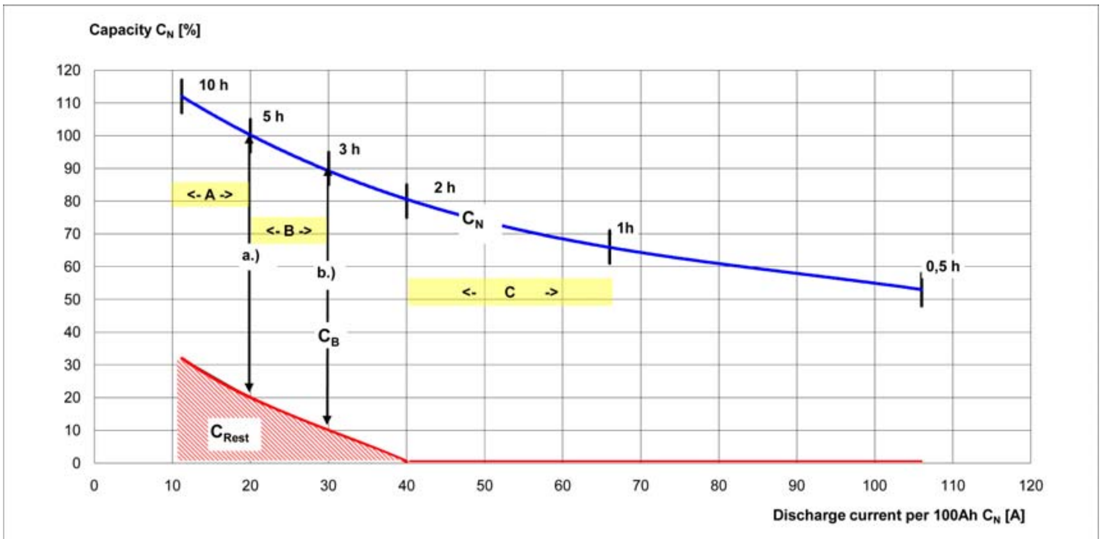
The adjustment of voltage based discharge indicators must be adapted to the individual application with the different developments of the discharge voltage and the battery type range.
In the following diagrams the available capacity and the curves of the open circuit and discharge voltage are shown in dependence of the discharge current and the discharge state for three typical application ranges (A, B, C):

<u>Application ranges</u>

A Tow tractors and transporters
typ. discharge time: 5 to 10 hours
typ. discharge currents: 10 to 20 A/100 Ah

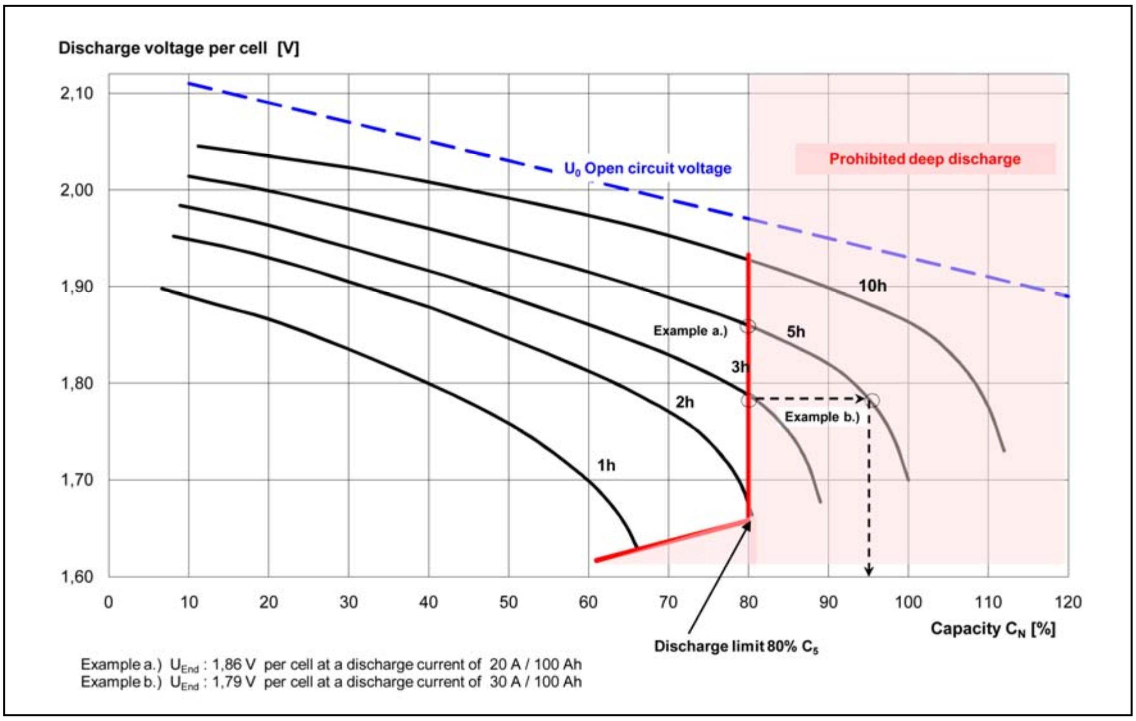
B Counterbalance trucks
typ. discharge time: 3 to 5 hours
typ. discharge currents: 20 to 30 A/100 Ah

C Semi traction, e. g. cleaning and sweeping machines
typ. discharge time: 1 to 2 hours
typ. discharge currents: 40 to 65 A/100 Ah

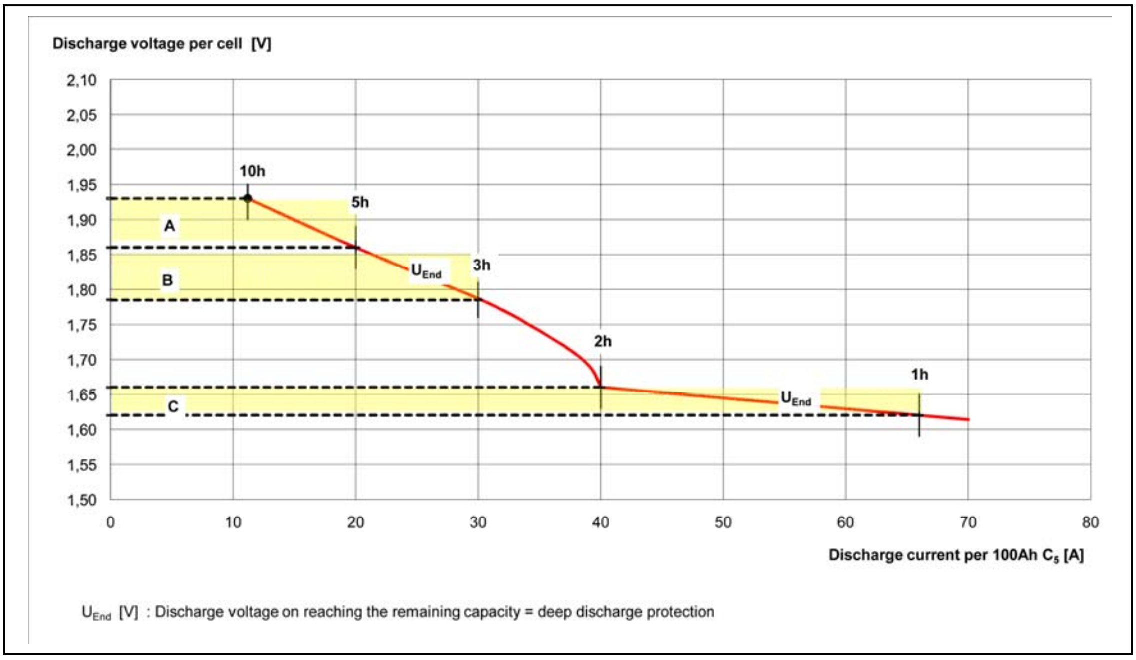


Capacity C_N [%]:	max. available capacity at 100% discharge
C_B:	permitted discharge capacity which can be taken from the battery at every discharge over the service
C_{Rest}:	remaining capacity, serves to protect against deep discharge

Picture 1: Capacity in dependence of discharge current (Recommended value for the PzS range)



Picture 2: Progression of the discharge voltage discharging with constant current in dependence of the depth of discharge (Recommended values for the PzS range)



Picture 3: Discharge voltage in dependence of the discharge current for the adjustment of the discharge indicator (Recommended value for the PzS range)

In practice only average values for the cut-off voltage (deep discharge protection) can be adjusted for the respective ranges. Through this inaccuracies arise. On the one hand not the complete available capacity can be used, on the other hand more than the available capacity may be discharged (deep discharge).

Example for the application range $\boxed{B}$ counterbalance trucks:
(see pictures 1 and 2)

Specified cut-off voltage under load for the battery range PzS:

Example a.) = 1.86 V/cell for the 5h-capacity with the average discharge current 20 A/100 Ah
Example b.) = 1.79 V/cell for the 3h-capacity with the average discharge current 30 A/100 Ah

Fault which leads to deep discharge:

Example b.)	preset:	1.79 V/Z for average discharge current 30 A/100 Ah
	real discharge current:	20 A/100 Ah

This leads to a discharge of 95% of the available capacity and therefore to a deep discharge (see picture 2).

For the above mentioned reasons discharge indicators must be adjusted according to the respective application and the related average discharge current and the battery type range according to the table below.

Cut-off voltages (deep discharge protection) in dependence of the average discharge current for different battery ranges
(recommended values)

Discharge	**p. 100 Ah_5[A]** equiv. n x I_5	**10** 0.5	**20** 1	**30** 1.5	**40** 2	**50** 2.5	**60** 3	**70** 3.5	**80** 4
Application range	**A**	Tow tractors a. transporters							
	B		Counterbalance trucks						
	C				Semi traction, e.g. cleaning and sweeping machines				
Cut-off voltage at									
80% DOD	**PzS [V/cell]**	**1.94**	**1.86**	**1.79**	**1.66**	**1.65**	**1.63**	**1.62**	**1.60**
	[V/24V battery]	23.28	22.32	21.48	19.92	19.80	19.56	19.44	19.20
	[V/48V battery]	46.56	44.64	42.96	39.84	39.60	39.12	38.88	38.40
	[V/80V battery]	77.60	74.40	71.60	66.40	66.00	65.20	64.80	64.00
60% DOD C_5	**PzV [V/cell]**	**2.00**	**1.96**	**1.92**	**1.87**	**1.84**	**1.79**	**1.74**	**1.68**
	[V/24V battery]	24.00	23.52	23.04	22.44	22.08	21.48	20.88	20.16
	[V/48V battery]	48.00	47.04	46.08	44.88	44.16	42.96	41.76	40.32
	[V/80V battery]	80.00	78.40	76.80	74.80	73.60	71.60	69.60	67.20
80% DOD C_5	**PzV [V/cell]**	**1.95**	**1.89**	**1.83**	**1.73**	**1.63**	**1.60**	**1.58**	**1.55**
	[V/24V battery]	23.40	22.68	21.96	20.76	19.56	19.20	18.96	18.60
	[V/48V battery]	46.80	45.36	43.92	41.52	39.12	38.40	37.92	37.20
	[V/80V battery]	78.00	75.60	73.20	69.20	65.20	64.00	63.20	62,00
80% DOD C_5	**GiS-bloc range [V/cell]**	**1,95**	**1.91**	**1.87**	**1.82**	**1.67**	**1.65**	**1.64**	**1.63**
	[V/ 6V bloc battery]	5.85	5.73	5.60	5.45	5.00	4.95	4.93	4.90
	[V/12V bloc battery]	11.70	11.45	11.20	10.90	10.00	9.90	9.85	9.80
80% DOD C_5	**GiV-bloc range [V/Zelle]**	**1.96**	**1.93**	**1.89**	**1.82**	**1.67**	**1.65**	**1.64**	**1.63**
	[V/ 6V bloc battery]	5.88	5.80	5.68	5.45	5.00	4.95	4.93	4.90
	[V/12V bloc battery]	11.75	11.60	11.35	10.90	10.00	9.90	9.85	9.80

Further influence factors as low temperature or battery aging effects, which result in a lower battery voltage level lead to reduced indication precision in the case of voltage based discharge indicators.

5. Discharge indicators for BATTERIEBUS-enabled battery controllers

These discharge indicators are based on the calculated state of discharge from the battery controller, evaluating the current level, the temperature and the battery range. In combination with the battery controller they represent by far the most precise discharge indicators in the market.

- The depth of discharge is indicated with the precision of a percent.
- Balancing of opportunity charges is possible. By this the requirements concerning a safe full charge detection and safety against manipulation are fulfilled.

6. What problems are found in practice?

The usual discharge time is not reached, respectively the discharge indicator shuts off too early

Reasons for this can be:
- the nominal capacity is not correctly dimensioned
- the battery has aged or is defect
- the cut-off voltage has been set to high
- The cut-off voltage has been adjusted to a wrong battery range
- The battery has been charged insufficient (undercharged)

Deep discharge despite usage of an discharge indicator

- This very often is only detected after a damage has occurred.

Indication for deep discharges can be:
- long charging times
- the Ah-count indicated at the charger is to high
- the charger does not start respectively goes into safety shut-off
- the electrolyte density at the end of discharge is lower than 1.13 kg/l (30°C)

Reasons for his can be :
- the battery is not immediately recharged. Here it comes to self discharge because of standing time
- the shut-off voltage is set to low
- the shut off voltage is set for another battery range
- the times to return to the charging station are to long
- the discharge indicator has been circumvented (manipulation)

Not paying attention to the signal “warning for deep discharge“

Especially critical are the consequences for discharge indicators which, at reaching the cut-off voltage, instead of shutting-off the lifting function, in part do a multistep current reduction. As the cut-off voltage is not adapted to lower currents deep discharges with capacity turnovers of more than 100 % are pre programmed.

7. Requirements for discharge indicators

- The discharge indicator should be protected from manipulation, i.e. the unplugging of the battery must not lead to a reset of the discharge indicator.

- The deep discharge signalling respectively shut-off of the lifting for counterbalance trucks at a depth of discharge of 80 % must be given in any case. An operation above that limit is not allowed. Longer drives back to the charging station require therefore a higher residual capacity than 20 %.

- A reset of the indication or the shut-off of the lifting must be only done after the recognition of sufficient charging or e.g. after reaching a predefined open circuit voltage over a set time or – in the case of on-board chargers – after reaching a defined charging voltage.

- Short term recuperation in the range of seconds, e.g. by using the braking or lowering energy of an industrial truck do not deliver a ampere hour charge that justifies a set back of the indication respectively the lift shut off

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