GOSSEN METRAWATT

STANDARDS-COMPLIANT TESTING OF STORAGE BATTERIES

BATTERY DIAGNOSTICS, MEASUREMENTS AND FUNCTION TESTS

STANDARDS-COMPLIANT, FUNCTIONAL TESTING OF STORAGE BATTERIES

THE BATTERY

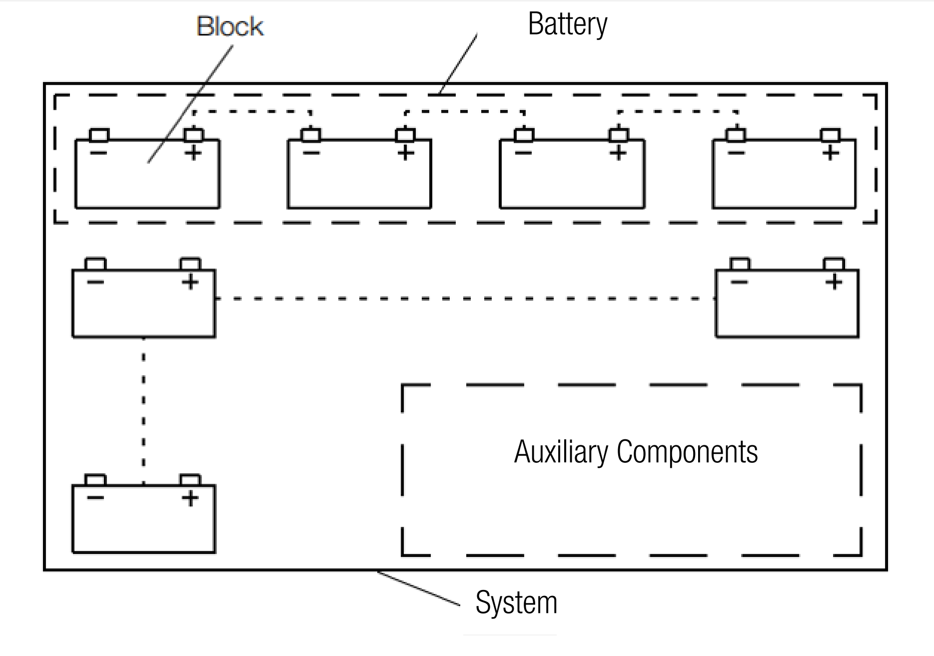
The term "battery" is derived from military parlance where it designates an assembly of several guns. Analogously, the term was adopted to describe an aggregate of several electrically connected galvanic cells. As of the second half of the 20th century, use of the term "battery" was also extended to include individual primary or secondary cells, although the term "accumulator cell" or "rechargeable battery" is more commonly used for the latter. The aforementioned shift in linguistic usage was addressed in **DIN standard 40729**, Accumulators; galvanic secondary cells; general terms and definitions, which defines a battery as "several connected cells", but this differentiation in terminology has become blurred in everyday usage.[1]

"Battery" is the generic term for energy storage devices, as well as the designation for any **primary battery**. Non-rechargeable batteries are called primary batteries. Batteries that can be recharged are called **secondary batteries** or **rechargeable batteries** in everyday language, and are also known as accumulators.[2]

Starter batteries for motor vehicles, traction batteries or deep cycle **storage batteries** for electric vehicles and stationary applications such as uninterruptible power supplies are always accumulators.

Appliance batteries are used to power small, mostly portable devices like watches, radios, toys, flashlights and the like, as well as permanently installed appliances such as smoke detectors. Standard designs are used in most cases.

Device batteries must be compact, suitable for use in any orientation, lightweight and yet mechanically robust. They mustn't leak or outgas during normal storage and use in the respective device. They're commercially available in numerous variants based on zinc-carbon or alkaline-manganese materials. Availability of zinc-carbon batteries has been decreasing since the 2000s, and they're hardly manufactured at all anymore.



Stationary Battery Layout

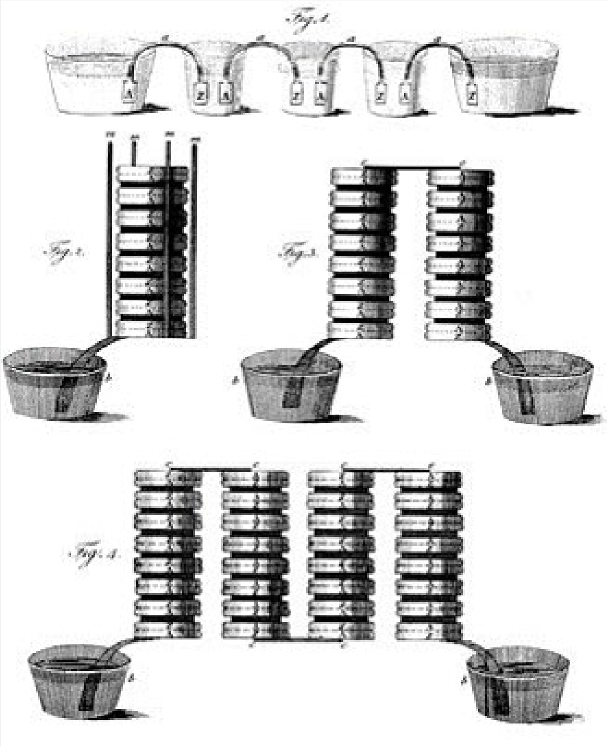
[1] Dirk Flottmann, Detlev Forst, Helmut Roßwag: Chemie für Ingenieure: Grundlagen und Praxisbeispiele
[2] zvei.org, October 2019

HISTORY OF THE BATTERY

Ancient vessel arrangements thought to be batteries, such as the “Baghdad battery”, would have been able to generate an electrical voltage of about 0.8 V through the interaction of copper, iron, and acid. Whether or not these vessels were used as batteries in the modern sense at that time, about 2000 years ago, is controversial and has not been proven conclusively.[3]

In 1780, Italian physician Luigi Galvani noticed that a frog’s leg that came into contact with copper and iron twitched repeatedly, and believed this to be an electrical effect.

The first functioning galvanic element, and thus the first battery, was invented by Alessandro Volta in 1800 in the form of the voltaic pile. Design improvements followed in subsequent years, such as William Cruickshank’s trough battery, which avoided the disadvantage of the voltaic pile’s vertical design. Historically, we differentiate between dry batteries with solid or gel electrolyte and wet batteries with liquid electrolyte.[4]



Historical wet batteries, which can only be operated in a certain orientation, include John Frederic Daniell’s Daniell cell by from the year 1836, along with several other variations and designs such as the gravity Daniell cell, John Christian Poggendorff’s Chromic acid cell from 1842, William Grove’s Grove cell from 1844 and Georges Leclanché’s Leclanché cell from 1866.[4]

These galvanic wet cells were used primarily to supply power to cable telegraph stations. Freely positionable dry cell batteries, which are still in use today, evolved from the Leclanché cell over the course of several development stages. Initial work in this area was conducted by Carl Gassner, who patented the dry cell battery in 1887.[5]

Paul Schmidt was the first to use the dry cell battery in flashlights in 1901 in Berlin.

Today’s most commercially significant batteries are predominantly secondary batteries[6], of which the lead-acid accumulator and the lithium-ion accumulator play the most important role.[7]

Due to their minimal cost, primary batteries are nevertheless still in demand for many smaller devices such as flashlights and watches. The alkaline manganese battery is the most economically significant primary battery.[8]

Modern Primary Batteries

[3] Riddle of “Baghdad’s batteries”. In: news.bbc.co.uk. BBC, 27 February 2003.
[4] William Edward Ayrton: Practical Electricity. Cassell, London. 1891, pp. 212 ff. (online).
[5] US patent 373,064: Galvanic Battery. Published on 15 November 1887, Inventor: Carl Gassner.
[6] The Global Battery Market – an Industry Report Review, Batteries, Climate Change and the Environment. 2 August 2014
[7] Battery Market Size & Share | Industry Report, 2020-2027
[8] Primary Battery Market | Growth, Trends, and Forecast (2020 - 2025). Retrieved on 16 October 2020 (English)

TESTING BATTERY SYSTEMS

Storage batteries are becoming increasingly important in terms of power supply security. However, they've been in use for many decades, especially – although not only – in the field of emergency power supply. But batteries are subject to irreversible, unavoidable aging processes during the course of time, which result in reduced available capacity. In order to ensure the availability of a stationary battery system's rated capacity, periodic testing and well-organized maintenance are necessary. The goal is to ascertain the battery's current condition and to pinpoint aged blocks before major damage occurs, thus impairing battery capacity.

Applicable	Directives and Standards
IEEE 450-2010	Recommended Practice for Maintenance, Testing and Replacement of Vented Lead-Acid Batteries for Stationary Applications
IEEE 1188-2005	Recommended practice for maintenance, testing and replacement of VRLA batteries for stationary applications
EPRI	Stationary battery guide: Design, application and maintenance
DIN IEC 21/455/CD: 1998-12	Guide for the use of monitoring systems for lead-acid stationary batteries
DIN EN 50272-2 VDE 0510-2:2001-12	Safety requirements for secondary batteries and battery installations (Adopted as DIN EN IEC 62485-2 as of April 2021)
DIN EN IEC 62485-2 (VDE 0510-485-2)	Safety requirements for secondary batteries and battery installations – Part 2: Stationary batteries

- **Relevant measurements in a UPS system:**
  - Alternating and direct voltage
  - Direct current
  - Internal Resistance
  - Acid Density
  - Temperature
- **VISUAL INSPECTION:** The rules set forth in the above-mentioned standards are applicable within this context.
- **FLOAT VOLTAGE:** All voltage values of the individual battery blocks within a battery system are recorded, often at mid-range intervals (inspection every 3 months).
- **CHARGING/DISCHARGING:** Block voltage values are recorded several times to this end, for example during a controlled discharge process. At least two test runs must be completed.
- **RESISTANCE:** In addition to measured values for block voltage (see FLOAT VOLTAGE), the associated internal resistance values of the battery blocks are also logged.
- **INTERVAL U / INTERVAL U + I:** Voltage and current curves during charging and discharging can be recorded at freely definable time intervals.
- **CONNECTORS:** Measurement of voltage drop across the connectors – also during discharge
- **TEMPERATURE:** Acquisition of block temperatures – frequently carried out together with float voltage measurement
- **DENSITY:** Density measurement of the electrolyte in the battery blocks (for vented batteries)

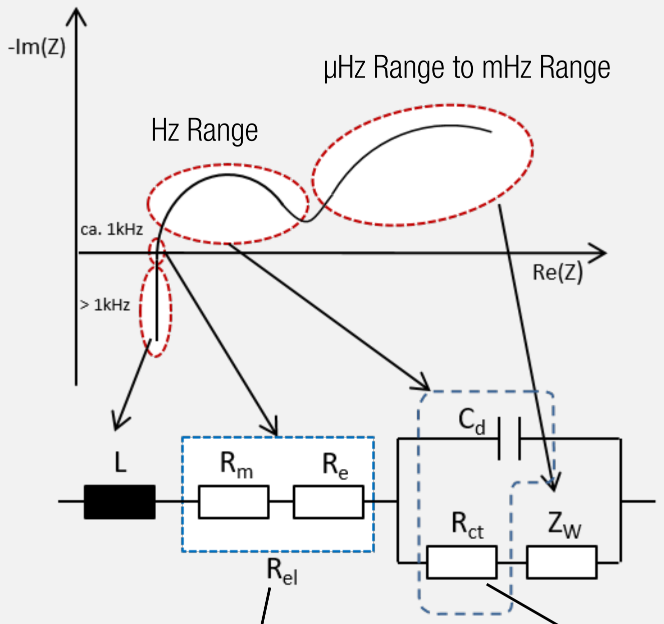
FLOAT CHARGING – Background

- Float charging is required for UPS applications in order to prevent self-discharge of the batteries.
- Gas bubbles form in the lead accumulator as of a voltage of 2.4 V per cell – the so-called gassing voltage. Corrosion of the electrodes is accelerated as a result, and oxyhydrogen gas may form during the course of prolonged overcharging.
- An ideal float voltage for lead-acid batteries with a corrosion-minimizing effect lies within a range of 2.20 to 2.25 V per cell.
- Temperature correction is required for critical applications. The correction factor for lead batteries ranges from -0.004 to -0.003 V/K.

INTERNAL RESISTANCE – SoH Indicator

- From the time of manufacture, lead-acid batteries begin to age irreversibly over the course of their service life.
- Internal resistance increases as the battery's components age.
- A battery's state of health (SoH) can be estimated based on how its internal resistance changes over time.
- As a prerequisite, internal resistance must be measured when the battery is installed so that the measured value can be used as a reference.

INTERNAL RESISTANCE – ELECTROCHEMICAL Model (for lead-based battery types)



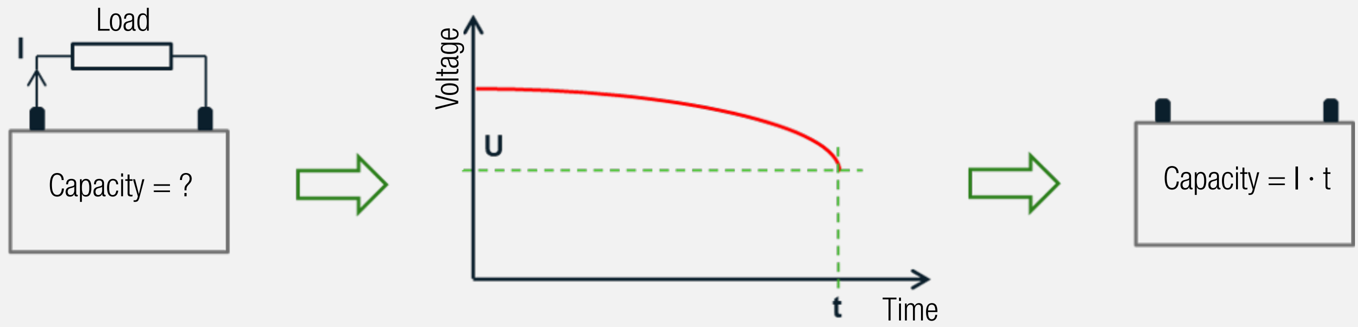
Indicators of aging effects:

- ► R_m: Corrosion effects, formation of dendrites
- ► R_e: Electrolyte condition
- ► R_{ct}: Quality and structure of the active plate material
- ► A battery's internal resistance increases as aging progresses.

DC Resistance $R_{el} + R_{ct}$
R_{ct}: Charge Transfer Resistance (resistance of the flow of cur rent at the interface between electrode and electrolyte)

AC Resistance R_{el}
R_m: Metallic Resistance (poles, plate straps, plate grids etc.)
R_e: Electrolyte Resistance

CAPACITY TEST – Background



Block-related: Charging/discharging

- Multiple measurement of block voltages during charging/discharging
- Measurement can be used to identify aged blocks on the basis of deviating voltage values (e.g. premature voltage drop during discharging).

Battery-related: Interval U / Interval U+I

- Recording of a complete battery charging/discharging sequence with regard to characteristic voltage and current curves
- Supplied/withdrawn ampere-hours can be determined. A battery's capacity is identified in this way.

CONNECTORS – Measuring Procedure

Measurement of voltage drop across the connectors

- Measurement must be performed while discharging.
- This measurement makes it possible to determine whether or not the blocks' connectors are damaged or haven't been adequately tightened.

TEMPERATURE – Background

The temperature of a cell is an important indicator of its state of health.

- Internal short circuits may occur due to corrosion or the formation of dendrites. Cell temperature is increased as a result. The increase in temperature causes the electrolyte to dry out more quickly, which in turn promotes corrosion processes. Increased corrosion means higher temperature -> thermal runaway (fire hazard).
- Short circuits often develop between individual plates. With constant float voltage, voltage applied to non-shorted cells increases and hydrogen is formed -> risk of explosion.

ACID DENSITY – Background

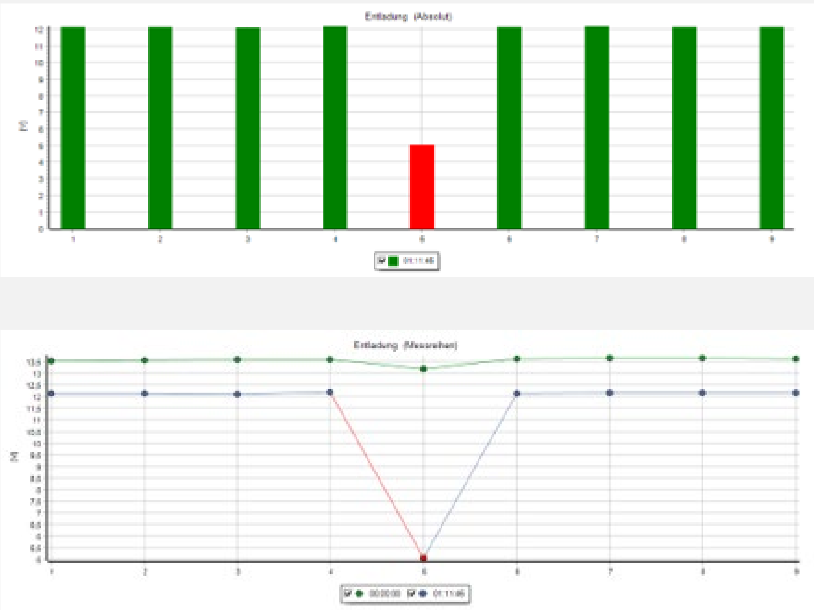
Determination of charge status by measuring acid density

- Vented lead-acid battery, acid density in fully charged condition: 1.22 to 1.26 kg per cubic meter (depending on battery type), in fully discharged condition: 1.1 kg per cubic meter
- Measurement of acid densities with fully charged batteries
- Comparison of acid densities of individual cells with each other -> identification of defective cells
- Measurement of the electrolyte's temperature

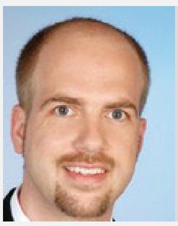
TEST INSTRUMENT FOR BATTERY TECHNOLOGY: the METRACELL BT PRO

Applications: Testing and maintenance of VRLA batteries and vented lead-acid batteries. Testing the battery for signs of mechanical aging (e.g. pole corrosion) and electrochemical aging (e.g. contact resistance from electrode to electrolyte).

- Visual inspections in accordance with applicable standards
- Periodic testing of UPS systems
  - Measurement of the float voltage in order to check for damage to battery blocks (increased power consumption)
  - Acquisition of voltage and current characteristics during battery discharge (with optional current clamp) -> capacity test at battery level
  - Measurement of block voltages during battery charging or discharge -> capacity test at block level
  - Determination of internal resistance for referential testing of lead-based battery blocks
  - Detection of block temperature via optional infrared sensor
  - Acquisition of acid density values in order to determine electrolyte quality (for vented batteries) – read-in via external measuring instrument
- Estimation of battery SoH (state of health) based on historical data (comparative values)



Visualized Evaluations of Measurement Data



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Printed in Germany • Subject to change without notice • 1/2.22 • 3-337-440-03