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Electric Vehicles Components Tests

Battery Technology

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Contents

0 Overview

The purpose of the current document is to analyse and characterize the existing battery technologies utilized in the common types of Electric Vehicles (EV). The document sums up the main characteristics of the cell technologies, as well as, their advantages and disadvantages.

0.1 Objectives

The main objectives of the document are defined as follows:

1. Build up the knowledge base for the common battery chemistries
2. Define and sum up main characteristics used for cell performance characterization
3. Classify the existing battery chemistries
4. Evaluate different battery technologies most commonly used in the electric vehicles
5. Characterize selected cells in terms and parameters specified in step 2
6. Provide benchmark tabular data for charge and discharge characteristics

1 Basic Battery Terms

A battery is a device that converts the chemical energy directly into electric energy by the means of an electrochemical reaction. In the case of rechargeable system, the battery is recharged by a reversal process [1].

The chapter provides a short overview over the common terms for the batteries performance characterization and batteries classification.

1.1 Battery Performance and Characterization

To be able to test and compare different battery technologies it is important to define the key characteristics of the battery performance. Those are defined below.

- **Cell, module, pack**
  A single cell is a complete battery including two terminals. The single cell usually consists of the two electrodes, separator and electrolyte. A module consists of several cells attached or welded to each other. A battery pack is composed of modules in one housing, usually also including battery management / thermal management electronics. EV and Hybrid Electric Vehicles (HEV) usually are equipped with high voltage battery packs, that consist of individual modules, where cells are organized in series or parallel.

- **Capacity or Nominal Capacity** (Ah for specific C-Rate)
  Ampere-hour capacity is the total charge that can be discharged from a fully charged battery under specified conditions. The manufacturers usually provide rated Ah capacity, which represents the nominal capacity of a fully charged new battery under conditions predefined by the manufacturer. The nominal condition can be e.g. $20°C$ and discharging 1/20 C-rate. Wh or kWh capacity can be calculated using the Ah multiplied by the rated battery voltage.

- **C-Rate**
  The C is used to represent a charge or discharge rate equal to the capacity of a battery in one hour. E.g. for the 1.6Ah rated battery, 1C discharge of 1.6A would fully discharge the battery within one hour. Also 0.5C equals 1.2A would fully discharge the battery within 2 hours, and 2C equals 3.2A would require 30 minutes to fully discharge the battery. The multiple of the C rate is calculated is follows:

  $$I = MC_n \tag{1.1}$$

  where

I= discharge current in A
C = numerical value of rated capacity of the battery in Ah
n = time, in hours, for which rated capacity is declared
M = multiple fraction of C

- **Specific Energy**
  Specific energy, also called gravimetric energy density, defines how much energy a battery can store per unit mass. The unit of the specific energy is Wh/kg.

- **Specific Power**
  Specific power, also referred as gravimetric power density of a battery, describes the peak power per unit mass, expressed in W/kg.

- **Energy Density**
  Energy density is also referred as the volumetric energy density, is the nominal battery energy per unit volume expressed in Wh/l.

- **Power Density**
  Power density, is the peak power per unit volume of a battery expressed in W/l.

- **Coulombic Efficiency**
  For a rechargeable battery the fraction of the electrical charge stored during charging that is recoverable during discharge. Sometimes, referred as Ah efficiency. Coulombic efficiency is not 100% because of losses in charge, largely caused by secondary reactions. The coloumbic efficiency of a battery is defined as follows:

$$\eta_c = \frac{Q_{out}}{Q_{in}} \tag{1.2}$$

  where Q_{out} is the amount of charge that exits the battery during the discharge cycle and Q_{in} the amount of charge that enters the battery during the charge cycle.

- **Internal Resistance**
  Internal resistance is the overall equivalent resistance within the battery. The internal resistance varies during charging, discharging processes depending on the operational conditions.

- **Cycle life**
  The number of the discharge-charge cycles the battery can be exposed before it fails the defined performance characteristics. Cycle life is usually specified for certain charge and discharge conditions. The actual lifespan of the battery depends on the operational conditions, rate and depth of cycles, temperature and humidity. High Depth of Discharge (DOD) reduces battery cycle life.

- **Terminal Voltage**
  The voltage between the battery terminals with the load applied. Terminal voltage varies with SOC and charge/discharge current.

- **Open Circuit Voltage (OCV)**
  The voltage between the terminals with no load applied. The open-circuit voltage depends on the battery SOC, increasing with higher SOC.

- **Nominal Voltage**
  The characteristic provided by manufacturer to describe the reference voltage of the cell.

- **Cut-Off Voltage**
  The minimum allowable cell voltage to indicate the lowest point of the SOC.

- **State of Charge SOC**
  The expression of the current provided battery capacity as percentage of its maximum capacity. The measurement of the SOC is challenging task and can be implemented either using OCV, current integration, impedance tracking or usually combination of those. The variation in the battery voltage from charged to discharged state is very small. The state of charge of battery can be defined as the available capacity as the percentage of the rated capacity.

$$SOC = \frac{AvailableCapacity[Ah]}{RatedCapacity[Ah]} * 100 \qquad (1.3)$$

- **Depth of Discharge DOD**
  The percentage of the battery capacity that has been discharged expressed as a percentage of its maximum capacity. A discharge to at least 80% SOC is referred as deep discharge.

- **State of Health (SOH)**
  SOH is the ratio of the maximum battery capacity of the aged battery to the maximum charge capacity of the new battery. SOH indicates the battery performance degradation and performance estimation in the remaining lifetime.

- **Maximum Continuous Discharge Current**
  The maximum current at which the battery can be discharged continuously. The limit is defined by the battery manufacturer to prevent high discharge rates which can damage the battery and reduce its capacity.In the EV this factor, along with the maximum continuous power of the motor defines the sustainable speed and acceleration of the vehicle.

- **(Recommended) Charge Current**
  The ideal current at which the battery is initially charged under constant charging scheme before transitioning into the constant voltage charging.

- **Charge Voltage**
  The voltage at which the battery is charge to when charged to full capacity. Charging schemes usually consist of constant current charging until the battery voltage reaching the charge voltage, then constant voltage charging, allowing the current to be minimized.

- **Battery Management System (BMS)**
  BMS is the battery supervising electronics, which usually includes sensors, controller, communication and computation hardware with according software, to control maximum charge/discharge current and duration from the estimation of the SOC and SOH of the battery pack. Some of the BMS include balancing circuitry for the control of the multiple cells.

1.2 SOC Determination

To be able to use a battery as power source it is crucial to know the amount of energy left in a battery compared to the fully charged state. This provides an indicator how much longer a battery will continue to perform before it needs recharging. SOC is often called **Gas Gauging** or **Fuel Gauging**. The manufacturer provided values are usually related to the rated capacity of a new cell. The cell capacity is gradually reducing with the cell ageing. Towards the end of the cell life its actual capacity will be approaching 80% of its rated capacity. Temperature and discharge rate are further factors influencing the effective capacity of the cell. The difference between the rated capacity and its actual capacity is crucial, since the real gas gauging applications (e.g. electrical cars) are relying on the correct SOC estimation. Often the SOC measurement reference is defined as current capacity instead of rated, in this case a fully charged cell, nearing the end of life, may still have 100% capacity, but would have the effective capacity of 80%. If an accurate estimation of remaining charge is required it is important to consider the battery ageing and environmental conditions.

1.2.1 SOC Measurement Accuracy

The knowledge of the SOC is important in almost all applications, but in particular in the automotive applications it is crucial, since the efficiency as well as safety must be guaranteed.

SOC in automotive applications

- **Electrical Vehicles** SOC is directly related to the driving range. It is an absolute value based on the new battery capacity, not the percentage of the current capacity, which could result in an error of almost 20%, due to the battery ageing. Current automotive fuel gauges are provide accuracy of an average of 95% [2].
- **Hybrid Electrical Vehicles** SOC is estimated when the engine is switched on and off. Errors of over 5% seriously affect the system fuel efficiency. An accuracy significantly better than 95% is therefore required [2].

1.2.2 Direct Measurement of SOC

Direct measurement would be the most precise possibility to measure SOC. The method is only applicable in case if the battery is discharged at the constant rate. In this case SOC equals current multiplied by the time this current flowed. In practical applications, this is not possible, since the discharge current is not constant but rather diminished as the battery becomes discharged, usually in non linear way. So an integration of the current over time is required. Secondly, the method requires to fully discharge the battery to know how much charge was contained. Except for testing purposes, this is not useful in real life applications.

Additionally, it is not possible to measure the effective charge of the battery by monitoring the actual charge put into battery, due the Coulombic efficiency of the battery. Losses occur during charge-discharge cycle, therefore the battery delivers less charge during discharge than was put in during charge.

1.2.3 Specific Gravity based SOC Measurement

The specific gravity is the customary way only used for the SOC estimation of the lead acid batteries. It depends on measuring changes in the weight of active chemical materials. As the battery discharges the active electrolyte, sulphuric acid, is consumed and the thus the its concentration is reduced. As a result the specific gravity of the solution is reduced in dependency to the SOC. Currently, this method is used with the digital measurement sensors within non sealed lead acid batteries. However, this method is unsuitable for other chemistries. For more specific details see section 3.1.5 [1].

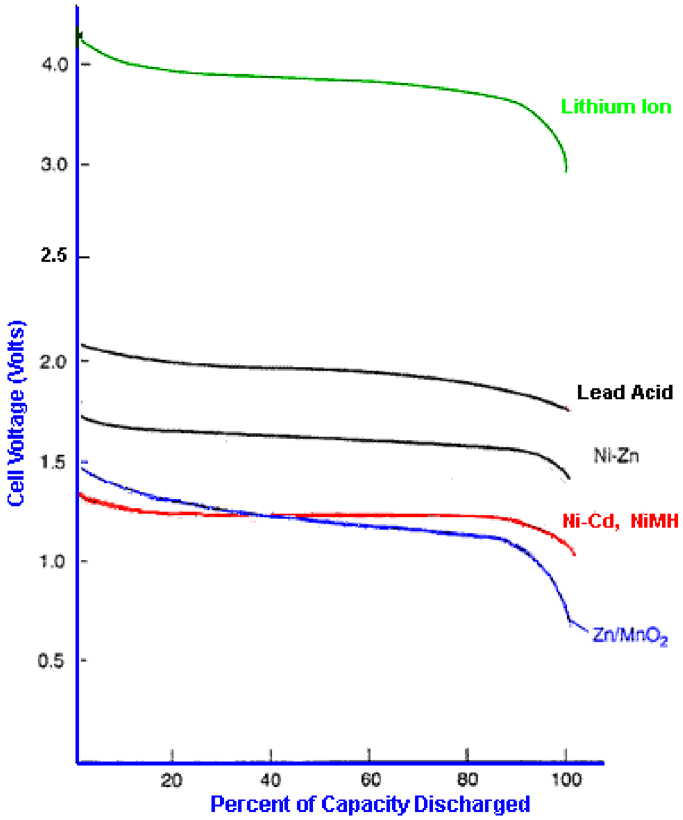
1.2.4 Voltage based SOC Measurement

Voltage based SOC estimation is the most broadly used and most low cost method within several battery chemistries. The method uses the cell voltage to calculate remaining SOC. The relationship between the OCV and remaining capacity is highly dependant on the battery chemistry, temperature, discharge rate, cell age, etc. E.g. higher temperature raises OCV and lower temperature lowers it. When measuring the OCV the battery voltage must be floating, with no load attached. In the most modern applications this is not the case. A parasitic load feeds the vital functions that causes the battery to dwell in a quasi closed circuit voltage condition (CCV).

For this reason this method, only considering the voltage of the cell is highly inaccurate. The most significant errors occur when the battery is being charged or discharged. This has a certain pull up/ pull down effect distorting the voltage values, which no longer represent the actual SOC. For this method to be accurate battery needs to reach an equilibrium state, by resting for at least 4-24 hours in the open circuit position. Equilibrium state neutralizes the voltage polarization effect. However, this is not reasonable in the most practical applications.

Each battery provides own discharge signature. While voltage-based SOC works well for the rested lead-acid batteries, the flat discharge curves of NiCd, NiMh, LiIon batteries makes this method very inaccurate. The problem with the discharge curves of those chemistries, is that those are very flat and almost 80% of the stored energy remains within this flat profile. This characteristic is very desirable as energy source but is a challenge for SOC estimation in the middle section of the SOC span, only indicating full charge and discharge precisely. The rapid fall in cell voltage at the end of the cycle can be used as an indication of imminent, complete discharge of the battery. For most of the applications an earlier warning is required, since deep discharge of the cell significantly shortens the cycle life.

Figure 1.1.: Battery Chemistries Discharge Curves Comparison [2]



In spite of the inaccuracies, most of the SOC estimations methods rely partly on voltage measurement due to its simplicity. Voltage based method is popular in wheelchairs, scooter and golf cars. Some of the modern BMS are using voltage readings as a part of their "learn" function.

1.2.5 Current based SOC Measurement

The energy contained in electric charge is measured in Coulombs and is represented as integral over the time of the current delivered by this charge. The remaining capacity is then calculated by measuring the current fed into and withdrawn from the cells and by integrating this value over time. The calibration reference point is fully charged cell, and the SOC is obtained by subtracting the current flow from it.

The method provides comparably high accuracy, since the charge flow can be measured directly. However, further effects such as ageing still has to be considered. Regular calibrations to bring chemical with digital battery in harmony are needed. To overcome the need of calibration, modern fuel gauges use learning functions, that estimate how much energy the battery delivered on the previous discharge. This allows a rough estimation on capacity.

Most common current sensing methods, such as current shunt, hall effect sensor, magneto-resistive sensors are commonly used.

Coulomb counting depends on the current flowing from the battery and does‘t consider self discharge currents or Coulombic efficiency of the battery. Further it is important to mention that in the automotive applications the current is sampled, and continuous current is reconstructed. In this cases sampling must be fast enough to capture the current peaks associated with acceleration.

According to the current state of charge, current based SOC measurement on new electric vehicle batteries may be off by 15% [2].

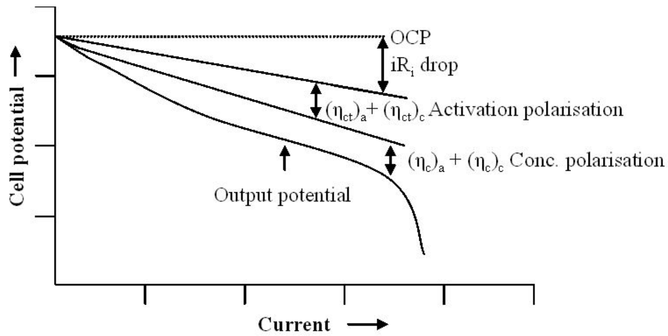
1.2.6 Internal Impedance based SOC Measurement

During the cell charge- discharge cycle the composition of the active chemicals in the cell changes as the chemicals are converted between the charged and discharged states. This results in the changes of the cell impedance. The measurements can be used to determine SOC, however these are not widely used due to difficulties in measuring the impedance while the cell is active as well as difficulties in interpreting the data since the impedance is also temperature dependent.

The internal impedance causes the voltage drop during the operation, and converts some of the useful energy into heat. The voltage drop caused by the internal resistance of the cell is referred as ohmic polarization, and is proportional to the current drawn from the system. The total internal impedance is the total sum of the losses occurring in the cell as resistance of electrolyte, electronic resistances of the active mass, the electrical lossess at the both electrodes and the contact resistance between the active mass and the current collector. All this resistance are ohmic and follow the Ohm‘s law, with the linear relationship between the current and voltage drop. As shown in the figure 1.2 the useful voltage delivered by the cell is reduced by the Internal Resistance (IR) drop.

Only at very small operating currents the polarization and IR losses are negligible, and the cell may operate close to the open circuit voltage, as a result delivering most of the theoretically available energy.

Figure 1.2.: Cell Polarization as a Function of Operating Current [1]



1.3 Practical SOC Measurement

In practical applications the performance of a typical cell can be measured and the results used to estimate the performance for the rest of the battery pack cells. The cell performance estimation is based on the look up tables, which are stepwise approximations of the discharge performance as a function of temperature, discharge rate and other parameters. This data is usually gathered in laboratory under controlled conditions. Once the cells are characterised the next step is to consider the battery cell performance in specific application.

1.4 Battery Classification

Electrochemical cells and batteries can be divided into primary (non rechargeable) and secondary (rechargeable), depending on the capability for recharge. Those two main groups can be further subdivided into chemistry dependant sub groups [1].

- Primary Cells
  This type can not be recharged electrically, are used once and discarded. The primary cells are cheap energy source for portable electronic and electric devices, lightning, etc. The general advantage of the primary batteries are good shell life, high energy density and little maintenance.

- Secondary Cells
  This type can be recharged electrically to the original condition after the discharge. Those are also known as accumulators. The applications for the rechargeable type of the batteries are very broad. On the one hand they are used as the energy storage devices, charged by the external power supply to provide energy to load on demand, e.g. automotive and aircraft systems, Uninterrupted Power Supply (UPS), electric vehicles, etc. On the other hand the batteries can be used as the primary cells but recharged after the use. Such an application are for e.g. portable consumer electronics, portable computers, power tools, etc.

1.5 Factors affecting battery performance

This section describes the generalized influence of different operational conditions on the performance of the battery. Within the given cell or battery design the performance differs from manufacturer to manufacturer. The more cell specific and manufacturer specified data will be described in 4.

1.5.1 Voltage Level

There are several definitions of the cell voltage:

- **Theoretical Voltage**
  Is the ideal case voltage curve, when the discharge starts and proceeds at the defined discharge rate until all active materials are consumed and the full capacity is utilized.

- **Open Circuit Voltage**
  Is the voltage under no load condition and is usually close to the theoretical voltage

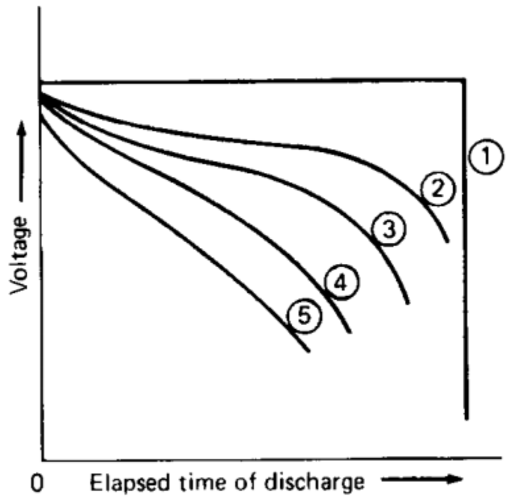
- **Closed-circuit Voltage**
  Is the voltage under the load condition
- **Nominal Voltage**
  Typical operating Voltage for the cell, e.g. 3.7V for Li Ion cells
- **Average voltage**
  The average voltage during the discharge
- **Cut-Off Voltage**
  Is the designated end of discharge, usually dependant on the application requirements. At the achieved cutt off voltage the most of the capacity has been delivered.

1.5.2 Current Drain

As the current drain of the battery is increased, the IR losses and polarization effects increase and the discharge voltage decreases, the slope of the discharge curve is steeper, and the service life as well as delivered ampere-hour or coulombic capacity are reduced. At extremely low current drain the discharge curve may approach its theoretical voltage and its theoretical capacity.

Higher current drains result in lower capacity achieved, since the cut off voltage is reached sooner. The same battery pack is usually able to provide additional capacity or service life after applying lighter load, since the battery voltage is able to regenerate. E.g. a battery pack used in a flash camera to its end-of-life (high-drain application) can be afterwards successfully used in a quartz clock application (much lower discharge rate).

Figure 1.3.: Characteristic Discharge Curves @ different Current Drains [1]



1.5.3 Mode of Discharge

The mode of discharge of a battery, among the other factors, has a significant effect on the performance of the battery. For this reason it is important to use the same discharge mode in a test as the one used in the application for which it is being tested. A battery discharged to a specific point (same closed-circuit voltage, same discharge current, the same temperature) will deliver the same ampere-hours to a load independent of the mode of discharge. However, the discharge current will be different depending on the mode of discharge. The service time or hours of discharge also differ.

Three basic modes for battery discharge can be differentiated:

Discharge Modes

- **Constant Resistance**
  The resistance of the load remains constant throughout the discharge (the current decreases during the discharge proportional to the decrease in the battery voltage)

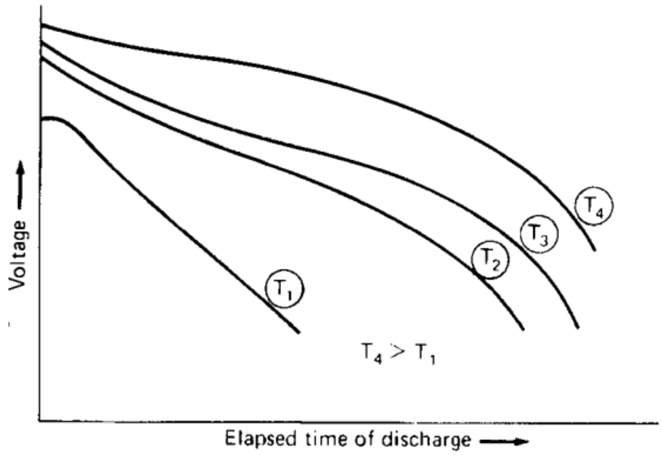
- **Constant Current**
  The current remains constant during the discharge

- **Constant Power**
  The current increases during the discharge as the battery voltage decreases, thus the battery is discharge at the constant power level

1.5.4 Temperature

The temperature at which the battery is discharged has a pronounced effect on its service life (capacity) and voltage characteristics. This effect is caused by the reduction of chemical activity and the increase in the internal resistance of the battery at lower temperatures. Lowering the discharge temperature will result in a reduction of capacity as well as an increase in the slope of the discharge curve. The specific discharge profile vary for each battery system, design and discharge rate, but generally best performance is obtained between 20 $^\circ$ and 40 $^\circ$ C. At higher temperatures, the internal resistance decreases, the discharge voltage increases and, as a result, energy output increases as well. On the other hand, chemical activity also increases at the higher temperatures and may be rapid enough during discharge to cause self-discharge and loss of the capacity.

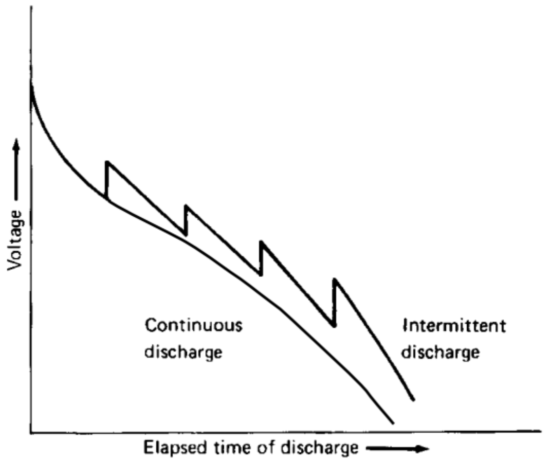
Figure 1.4.: Characteristic Discharge Curves @ different operational Temperatures[1]



1.5.5 Type of Discharge

When a battery stands idle after a discharge, certain chemical and physical changes take place which can result in a recovery of the battery voltage. Thus the voltage of a battery, which has dropped during a heavy discharge, will rise after a rest period, giving a sawtooth-shaped discharge. This results in increased service life. This improvement, resulting from the intermittent discharge, is generally greater after the higher current drains (as battery has the opportunity to recover from polarization effects).

Figure 1.5.: Characteristic Discharge Curves @ different Types of discharge [1]



Another consideration is the response of the battery voltage in case the discharge current is changed during the discharge process, such as changing loads. In this case it is important to mention that service life of the battery is determined when the cut off voltage is reached under the higher discharge load. The average current cannot be used to determine the service life. Operating at two or more discharge loads is typical for certain electronic equipment, due ot the different functions it has to perform. Such examples are higher rate periodic pulse requirement against lower background current, such as back lighting LCD watch application, the audio trouble signal pulse in the operation of a smoke detector, or a high-rate pulse during the use of a smart-phone.

1.5.6 Internal Resistance

Internal resistance IR is defined as opposition or resistance to the flow of an electric current within the cell. The total IR is the sum of the ionic and electronic resistances of the cell components. IR varies with battery size, construction, temperature, age and DOD of the battery.

- Electronic Resistance
  Electronic IR defines the total resistance of the materials of the construction: metal covers, carbon, conductive cathode materials, etc.
- Ionic Resistance
  Ionic IR defines resistance occurring due to the electrons movement within the cell. These include electrolyte conductivity, ionic mobility, electrode porosity, electrode surface area, etc.

A battery cell has resistive, capacitive and inductive resistances resulting in the battery impedance, according to the Randles battery model. The inductive battery resistance is often omitted due to the negligible magnitude. For the measurement of the battery IR several methods exist.

- DC resistance
  Current step is applied to the pre-charged battery cell and the voltage drop is measured. Resistance is calculated as

  $$IR(SOC, t_s) = \frac{U_{OCV} - U_p}{I_{discharge}} \quad (1.4)$$

  where U_{OCV} is the initial stabilized cell voltage and the U_p is the voltage drop due to the applied pulsed load. The calculated IR is a strong function of the applied current puls duration and amplitude, increasing with higher amplitude and pulse duration.
- AC resistance
  AC IR applies an alternating current into the battery cell. The capacitive and inductive reactance is minimized and the resistance is calculated similar to the DC resistance method. DC load test is preferred for batteries powering DC loads.

DC method provides purely resistive value at zero frequency, Impedance includes reactance measured with AC. Both methods provide different IR values, but both are correct. Depending on the battery cell application the according IR should be taken into account.

In this document only the DC current pulse method for the IR measurement will be performed.

2 Batteries Selection

2.1 Commonly used battery chemistries in electric vehicles

The requirements of the EV batteries is quite different from those used in the consumer electronics. The main requirements include handling high power in kWh range and providing high energy capacity within limited space and weight. Additionally, affordable price is a precondition for the commercial success.

The EV, dependent on the degree of the electrification, can be divided into:

- **HEV**
  HEV are vehicles with two or more power sources in the drive train. Current hybrids use both conventional combustion engine and a battery / electric drive system.
  - **Micro**
    Include some sort of start-stop system to shut of the combustion engine while idling.
  - **Mild**
    Combine the conventional engine with the electric machine (motor/generator), allowing to shut down the engine while braking, coasting or stopped. Mild Hybrids utilize regenerative braking or some level of power assistance for the combustion engine, but do not provide full-electric mode.
  - **Full**
    Vehicles that car run on the conventional combustion engine, just batteries or the combination of both.
- **PHEV**
  Plug-in Hybrid Electric Vehicles (PHEV) is a hybrid EV which uses rechargeable batteries, which can be charged externally, by plugging to power source, e.g. electric wall socket.
- **BEV**
  Battery Electric Vehicles (BEV) utilizes only rechargeable battery packs as the energy storage with only electric and motor controllers instead of the conventional combustion engines.

The main battery technologies utilized in electric vehicles of selected car manufacturers (as of June 2015) are summed up in the table 2.1:

The two most broadly used battery technologies in the EV are Nickel Metal Hydrid (NiMH) and Lithium Ion (Li-Ion). NiMH is a mature and well understood battery technology, for this reason a predominant number of the HEV on the market utilizes NiMH. On the other

Table 2.1.: Battery Technology in Electric Vehicles, adapted from [3]

Manufacturer	Country	Vehicle model	Type	Battery Technology
GM	USA	Chevy-Volt Chevrolet Spark EV Saturn Vue Hybrid	PHEV BEV HEV	Li-Ion Li-Ion NiMH
Ford	USA	Escape Fusion MKZ Focus Electric	HEV / PHEV HEV HEV BEV	NiMH / Li-Ion NiMH NiMH Li-Ion
Toyota	Japan	Prius	HEV/PHEV	NiMH/Li-Ion
Honda	Japan	Civic Hybrid Insight FIT EV	HEV HEV BEV	NiMH NiMH Li-Ion
Hyundai	South Korea	Sonata	HEV	Li-Po
Chrysler	USA	Chrysler 200C EV	PHEV	Li-Ion
BMW	Germany	X6 ActiveHybrid i3 i8	HEV BEV PHEV	NiMH Li-Ion Li-Ion
BYD	China	E6 Qin	BEV PHEV	LiFePo4 LiFePo4
Daimler Benz	Germany	ML450 S400 Smart Fortwo ed Mercedes-Benz BlueZERO	HEV HEV BEV BEV/PHEV	NiMH Li-Ion Li-Ion Li-Ion
Mitsubishi	Japan	iMiEV Outlander	BEV PHEV	Li-Ion
Nissan	Japan	Altima Leaf EV	HEV BEV	NiMH Li-Ion
Renault	France	Twizy Fluence Z.E. Zoe	BEV BEV BEV	Li-Ion Li-Ion Li-Ion
Tesla	USA	Roadster/ Model S	BEV	Li-Ion
Think	Norway	Think City EV	BEV	Li-Ion
KIA Motors	South Korea	Soul EV	BEV	Li-Po
Volkswagen	Germany	e-Golf Golf GTE e-Up! Audi A3 Sportback e-tron	BEV PHEV BEV PHEV	Li-Ion Li-Ion Li-Ion Li-Ion
Volvo Cars	Sweden	C30 DRIVe Electric V60 PHEV	PHEV PHEV	Li-Ion Li-Ion

hand the number of the EV powered by the Li-Ion batteries is rapidly growing. The Li-Ion battery technology offers several crucial advantages over the maturity of the NiMH such as higher specific energy and energy density. Even though Li-Ion and NiMH technologies are dominating the EV market, the Lead-Acid-Battery remains the workhorse of the industry. Those are used in UPS, robotics and applications where weight factor is not crucial.

2.2 Commonly used battery chemistries in e-bikes and pedelecs

The requirements for the battery technology built into the electrical e-bikes are quite similar to those of the EV. According to the European Commission [4] Electrical Bike (e-bike)s and **pendelec!** (**pendelec!**)s belong to the Light Electric Vehicle (LEV) weight class (less or equal 400 kg). Within the LEV two different types can be differentiated:

- **pendelec!**
  Cycles equipped with electrical motor, can not be purely operated by the motor. The motor provides assistance to the cyclist while pedalling.

- **e-bike**
  Cycles equipped with electrical motor, which can be purely operated by the motor. It is not necessary for the cyclist to pedal.

All electric bicycles (e-bikes and **pendelec!**s) are a subject of the type approval according to the [4] with the one exception: **pendelec!** with pedal assistance, equipped with electric motor with maximum continuous rated power of 250W and maximal assistance up to speed of 25 km/h.

Electric bicycles exceeding this specifications have to be type approved. The type specifications are regulated by [5], defining electric bikes in vehicle category L1e, which is subdivided into L1e-A "powered cycles" and L1e-B "mopeds".

According to the described classification almost 95 percent of the electrical bicycles on the market belong to the **pendelec!** class with the 25km/h and 250W continuous rated power limitations.

In Austria the electric bicycles are regulated by the [6] and [7], defining the **pendelec!** class with 600W continious rated power and 25km/h. Speed **pendelec!**s (S-Pendelecs) with assistance with up to 45 km/h are not authorized.

Since several types of the e-bikes provide different degree of the assistance, 3 modes of the electrical bicycles can be defined.

- **Pedal Assist**
  The electric drive is activated by the pedalling action of the cyclist. The class includes described above **pendelec!**.

- **Throttle on Demand**
  The electric drive system is activated by the throttle element such as grip-twist.

- **Speed pendelec!**
  The electric drive system is activated through pedalling and is able to achieve higher speeds.

The main battery technologies utilized in electric bikes and pendelecs of selected manufacturers (as of June 2015) are summed up in the table below:

Table 2.2.: E-Bike Systems Battery Packs

Manufacturer	Country	Voltage	Capacity	Battery Technology
BionX	Canada	48V 36V 24V	6.6 Ah / 8.8 Ah 9.6 Ah 8 Ah	Li-Ion Li-Ion NiMh
Schimano	Japan	36V	11.6 Ah	Li-Ion
Bosch	Germany	36V 36V	8.2 Ah 11 Ah	Li-Ion Li-Ion
Yamaha	Japan	36V	11.1Ah	Li-Ion

2.3 Commonly used Cell Sizes

Most commonly battery packs built into the car or e-bike consist of singular cells combined in series and parallel. Depending on the battery chemistry there are different standardized cell sizes.

For the Li-Ion cells the most broadly used cell size is the cylindrical cell with the nominal voltage of 3.6V. Those cells is known as 18650, which refers to its dimensions diameter x length 18.6 x 65.2 mm. The capacity of the cell is in the range of 1500-3400 mAh. Those cells are used in a number of applications, in particular in several e-bike battery packs, Tesla Model S, etc.

By the cells one usually refers to the unprotected cells without built in protection electronics. Protected cells provide under-voltage protection electronics, causing increased size of the cell.

LiFePo4 unprotected cells are usually built in the same size as the Li-Ion cells or slightly bigger in 26650 size.

Lithium Polymer (Li-Po) batteries on the other hand are packed into pouches of different sizes, packaged in a bag using laminated architecture. The voltage per cell is 3.7V. Those cells have the potential to increase the energy density compared to the cylindrical cells, however, the manufacturing technology is not mature enough, resulting into higher costs than the 18650 cells. For the NiMH and NiCd battery technologies the sizes vary, however, the most broadly used sizes in the EV are either C, D or Sub-C. Table 2.3 provides overview over the used cell sizes.

2.4 Cells selection

Based on the previously described battery technologies used in the EV and e-bike / **pendelec!**s and on the most common cell sizes within the battery technology several cells has been selected for the test purposes. The cells and it specification can be found in the table 2.4 below.

Table 2.3.: Most commonly used Cell Sizes

Size	Dimension [mm]	Battery Technology	Voltage per Cell
F cell	33 x 91	NiCd, NiMH	1.2V
D cell	34.2 x 61.5	NiCd, NiMh	1.2V
C cell	25.5 x 50	NiCd, NiMh	1.2V
Sub-C	22.2 x 42.9	NiCd, NiMh	1.2V
A cell	17 x 50	NiCd, NiMh	1.2V
AA cell	14.5 x 50	NiCd, NiMh	1.2V
AAA cell	10.5 x 44.5	NiCd, NiMh	1.2V
AAAA cell	8.3 x 42.5	NiCd, NiMh	1.2V
9V battery	48.5 x 26.5x 17.5	NiCd, NiMh	9V
18650	18 x 65	Li-Ion	3.6V
26650	26 x 65	LiFePo4	3.2 V
14500	14x 50	Li-Ion	3.6V

Table 2.4.: Batteries selected for testing

Manufacturer	Type and Description	Battery Chemistry	Cell Size /[mm]	Nom. Cell Voltage [V]	Nom. Capacity [mAh]	Max. Discharge Current [A]
Samsung	ICR 18650 22P	Li-Ion (LiNiMnCoO2)	18650	3.6-3.7	2150	10
Samsung	INR18650 25R	Li-Ion (LiNiMnCoO2)	18650	3.6-3.7	2500	20
Panasonic	NCR18650A	Li-Ion (LiNiCoAlO2)	18650	3.6-3.7	3100	6.2
Sony	US18650V3	Li-Ion (LiNiMnCoO2)	18650	3.6-3.7	2250	10
A123	APR18650MA1	LiFePo4	18650	3.2-3.3	1100	30
Panasonic	N-1250SCRL	NiCd	4/5Sub-C	1.2	1200	-
Panasonic	KR-1800SCE	NiCd	Sub-C	1.2	1800	-
Emmerich	255002	NiMH	Sub-C	1.2	2400	48
Panasonic	HHR-260SCP/FT	NiMH	Sub-C	1.2	2450	20
Conrad Energy	HYSS613	VRLA	B x H x T 97x51x25	6	1200	-
Yuasa	NP1.2-12	VRLA	B x H x T 97x48x55	12	1200	8.4

3 Battery Chemistries Characterization

3.1 Lead Acid

3.1.1 Chemistry and Construction

The basic chemistry consists of the porous lead (Pb) on the negative electrode and lead-dioxide (PbO_2) on the positive electrode, as the electrolyte sulfuric acid (H_2SO_4) is usually used. The conduction of the energy occurs within the electrolyte via the migration of the ions. The evaluation of the chemical processes at the electrodes is beyond the scope of this document. Generally, both sub-reactions at positive and negative electrodes cause the building of the lead-sulfat ($PbSO_4$) at the electrodes, which has poor conductivity. Additionally the concentration of the acid electrolyte is reduced. This fact makes the concentration of the electrolyte in the battery a good indicator for the battery charge status.

- Battery voltage at zero current
  The reactions at both electrodes result in the voltage difference at positive and negative electrodes. Nominal open circuit voltage of the single cell at full charge at approx. $25°C$ is 2.10V. Open circuit at full discharge is 1.95V. The temperature is in important factor, influencing the voltage and state of the charge.

- Discharge through external load
  External load causes chemical reaction and electron flow from negative to positive terminals. The current flows through the electrolyte to complete the circuit. The internal resistance of the electrolyte is influenced by the conductivity of the electrolyte and the contact resistance. The internal resistance is strongly dependant on the temperature and state of charge.

- Charge from external load
  External source causes chemical reaction and electron flow from positive to negative terminals. The chemical reactions are inverted converting electrical energy into stored chemical energy. In charged state the lead-sulfate coating of the electrodes is minimal and the electrolyte concentration is maximal.

Depending on the application area of the lead-acid battery, two different types can be differentiated:

- Starting light ignition (SLI)
  This type is designed to deliver quick bursts of the energy. The plates within the battery are thin with high surface area to reduce the resistance.

- Deep Cycle
  This type provides less instant energy, but greater long term energy. The plates are thicker for longer cycling.

Depending on the electrolyte characteristics, 3 sub categories can be defined:

- Wet cell (flooded)
  Wet cell has liquid sulfuric acid as electrolyte. The battery can be serviceable and maintenance free (sealed), also referred as Sealed Lead Acid (SLA).

- Gel Cell
  Has the silica gel type electrolyte, also known as Valve Regulated Lead-Acid (VRLA). The type is most sensitive for the overcharge.

- AGM
  Absorbed Glass Matt type uses glass mat as electrolyte. The advantages include faster charging and instant high currents on demand.

The construction of the most common 12V VRLA consists of 6 cells connected in series, each cell is composed of positive and negative electrodes connected in parallel, and immersed into the electrolyte. In case of the VRLA the container (polymer) of the battery pack is equipped with pressure relief safety valves.

3.1.2 Charge Characteristics

Charging process of the Lead-acid battery is a simple process, compared to more complicated cell chemistries such as Li-Ion. Simple constant current, constant voltage are often applied. Nevertheless, several important points has to be considered. In case if the SLA battery is over-charged, the excess cell voltage results in the conversion of the electrolyte into large amounts of gasses, which can not be recombined as in normal case. In case if the SLA battery is under-charged, the low cell voltage causes the charge current to diminish to zero before full capacity is reached. This produces additional lead sulphate on the plates and diminishes capacity permanently. A number of methods for charging SLA batteries can be applied to prolong the battery life. The basic methods are briefly described below:

- Constant-current
  Fixed current is applied for a certain time to the battery to recharge it. For the common 12V battery, the value of the current is set low (usually less than 0.4C), the charging process requires takes more time (dependant on the number of cells). The voltage has to be maintained at 2.45V per cell at a room temperature, with the charging time 6-12 hours. The method is used for charging of single cells, but is not common for the multiple cells in series, because of gassing which may occur when overcharged and cell balancing is required.

- Constant-voltage
  A fixed voltage is applied to the battery, the charging current is at its maximum. The method is seldom applied for charging cyclic charge-discharge applications (e.g. battery in electric vehicle). It is commonly used method to maintain the charge used in standby applications (e.g UPS). For a standard cell with nominal OCV of 12V, the battery is charge by applying 2.45V per cell at room temperature. The charging is

complete when the charge current remains stable for three hours. Exact voltage control is required and proper charging time is essential for battery life.

- Modified constant voltage
  In the charging process both constant initial current and constant finishing charge rate float charging are used. The charging starts with a constant current until certain voltage is reached (gassing voltage). Charging process continues with constant-voltage, equal to gassing voltage or slightly below, until the current decreases to a value of about 0.1C. At this point the constant-voltage is reduced to the float voltage to maintain the battery charge.

- Float
  The constant voltage is applied sufficient to finish battery charge or to maintain the full charge. The voltage is controlled from 2.15-2.3V per battery cell. The method is often used in stationary applications, such as UPS.

- Trickle / Standby
  The battery is kept charged with small current (0.01C) for compensating self-discharge. The battery is disconnected from load.

3.1.3 Discharge Characteristics

Discharge performance of the lead acid battery depend on discharge rates. Higher service capacity is obtained at the lower discharge rates. At higher discharge rates, electrolyte in the power structure of the plates becomes depleted and the electrolyte cannot diffuse rapidly enough to maintain the cell voltage. Intermittent discharge allows electrolyte to recirculate improving the high rate performance. In general, lead acid batteries may be discharged without harm at any rate of current it can deliver, but discharge should not be continued beyond the point where the cell approaches exhaustion or where the voltage falls below the useful value.

3.1.4 Temperature characteristics

The effect of the temperature on the lead acid battery shows reduced life as result of an increase in the rate of corrosion. The optimum operating temperature or lead-acid battery is 25°, as a guideline every 8° rise in temperature will cut the battery life in half. VRLA which has an average operational life of 10 years will only last 5 years if operated at 33°.

3.1.5 SOC Measurement

Specific Gravity Method

Specific gravity of the electrolyte gives the concentration of acid in electrolyte. As the battery discharges the active material is consumed and the concentration of active material, i.e. sulphuric acid in the electrolyte decreases. The traditional way of measuring the SOC, involves the measurement of the specific gravity (density) of the electrolyte using hydrometer. This indicator is quite accurate, especially when corrected by temperature. The measurement of the modern sealed batteries is however impossible.

Figure 3.1.: Characteristic Discharge Curves of Lead Acid Battery @ different discharge rates [2]

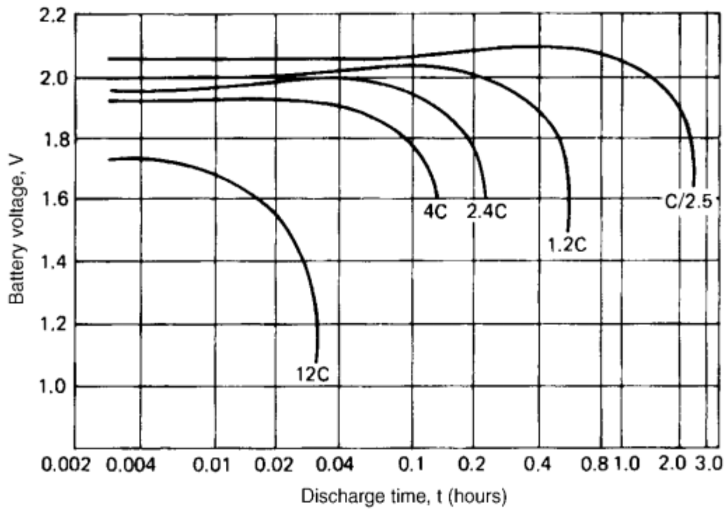


Figure 3.2.: Temperature Effect on the Discharge Curves (@1C) of Lead Acid Battery[3]

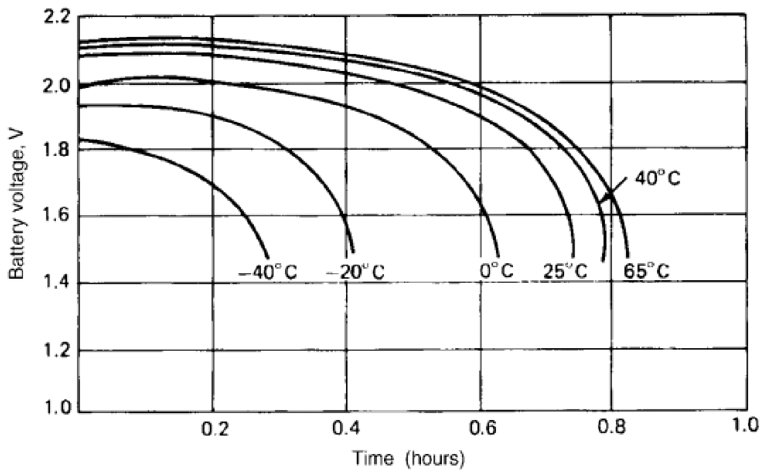


Table 3.1.: Lead Acid SOC estimation vs Specific Gravity and Cell Voltage [2]

Approximate SOC	Average specific gravity	Open circuit voltage			
		2V	6V	8V	12V
100%	1.265	2.10	6.32	8.43	12.65
75%	1.225	2.08	6.22	8.30	12.45
50%	1.190	2.04	6.12	8.16	12.24
25%	1.155	2.01	6.03	8.04	12.06
0%	1.120	1.98	5.95	7.72	11.89

OCV Method

For practical measurement the OCV is used as indicator, however there is no linear correlation between OCV and SOC. The SOC of lead acid battery is a semi-linear function of the open circuit voltage. Although the OCV method is known as an accurate indicator of SOC, this method cannot be regarded as a real-time monitoring strategy as the voltage readings take much time to stabilize. The OCV is only representative for the SOC if measured in equilibrium state. Results of this method can vary depending on the measurement conditions, e.g. actual voltage level, temperature, discharge rate and the age of the cell. The basic procedure for the measurement of the SOC can be implemented using following procedure [8]:

OCV based SOC calculation

1. Measurement of the OCV in equilibrium state
2. Temperature correction
3. Subtraction of the temperature-corrected voltage from the full charge voltage (manufacturer data)
4. Calculation of the voltage decrease into SOC percentage

Estimating SOC requires following values assumed or specified:

Values required for SOC estimation

- Full-charge OCV voltages for batteries @ 25°
  - 12.80 V for SLA including Absorbent Glass Mat (AGM)
  - 12.65 V for non-sealed batteries
- At constant temperature OCV decreases by about 0.01 V / 1.2% SOC discharge
- Temperature effects on voltage are approximated by:
  - +30 ° $\rightarrow$ -0.01 V
  - +20 ° $\rightarrow$ 0 V
  - +10 ° $\rightarrow$ +0.03 V
  - -1 ° $\rightarrow$ +0.03 V
  - -15 ° $\rightarrow$ +0.13 V

Coulomb Counting Method

Current integration method (direct method) is a simple process of summing up the capacity taken out the battery or put into the battery. The method works well for relatively small times spans. Using this method over long period of time will result in the accumulation of error.

Table 3.2.: Lead Acid SOC estimation vs OCV [8]

	Open circuit voltage			
Approximate SOC	2V	6V	8V	12V
100%	2.10	6.32	8.43	12.65
75%	2.08	6.22	8.30	12.45
50%	2.04	6.12	8.16	12.24
25%	2.01	6.03	8.04	12.06
0%	1.98	5.95	7.72	11.89

3.1.6 Main areas of application

Lead acid batteries are used in the broad variety of applications, in the past several years a number of new applications have arisen. The areas of application can be divided into following main areas [1]:

1. Automotive Applications
   Most common use case for starting, lighting and ignition in vehicles with internal combustion engine. Almost all of these use 12V nominal electric system. High cranking ability at low temperatures is still major design factor along with the cycling factor due to the electronics. Size and weight reduction have also become important as well as the battery geometry. This lead to the redesign of traditional flooded lead acid battery to the semisealed, maintenance free construction.

2. Small Sealed Lead Acid Cells
   There has been a significant increase in the use of battery operated consumer equipment such as portable tools, lightning devices, instruments, photographic equipment, toys, etc. Batteries in these applications have generally low capacity up to 25Ah. The small sealed or semi-sealed lead acid cells are available as single 2V units or as multiple cell units usually in 6V monoblock.

3. Industrial Applications
   The industrial applications of lead acid batteries can be divided into automotive and industrial designs. The automotive applications include traction in vehicles, or emergency lighting, photovoltaic or sealed cells for tools, instruments, other electronic devices. The industrial design include switch gears, railway signals, UPS, industrial trucks, large electrical vehicles, etc.

4. Electric Vehicles Although, there have been several attempts to design completely lead acid battery based electric vehicle, the introduction of the Ni-Mh batteries made the usage of heavy lead acid cells obsolete.

3.1.7 Advantages and Disadvantages of Lead Acid Batteries

Advantage	Disadvantage
Popular low cost battery	Relative low cycle
Large quantities available	Limited energy density
High-rate performance	Challenging storage (degradation of the electrodes)
Good high and low temperature performance	Explosion hazard due to hydrogen
Electrically efficient	Thermal runaway hazard in improper charging
High open circuit voltage	
Easy state-of-charge	
Low cost	
Easy recycling	

3.2 NiMH

3.2.1 Chemistry

The NiMH battery is an alkaline storage battery, electrically very similar to NiCd. The active materials in the NiMH are composed of $Ni(OH)_2$ nickel hydroxide on the positive electrode, hydrogen stored in the metal hydride structure on the negative electrode and alkaline electrolyte (usually potassium hydroxide) as electrolyte.

- Charge
  At the negative electrode, in the presence of the alloy and with an electrical current applied, the water in the electrolyte is decomposed into hydrogen atoms, which are absorbed into the alloy. At the positive electrode the charge reaction is based in the oxidation of nickel hydroxide. The positive electrode releases hydrogen into the electrolyte.

  Positive electrode

  $$Ni(OH)_2 + OH^- \rightarrow NiOOH + H_2O + e^- \tag{3.1}$$

  Negative electrode

  $$M + H_2O + e^- \rightarrow MH + OH^- \tag{3.2}$$

  Overall reaction

  $$Ni(OH)_2 + M \rightarrow NiOOH + H_2O + MH \tag{3.3}$$

- Discharge
  When NiMH cell is discharged, the chemical reactions are the reverse of what occurs while charged. Hydrogen stored in the metal alloy of the negative electrode is released into the electrolyte to form water. This water then releases a hydrogen into that is absorbed into the positive electrode to form nickel hydroxide.

3.2.2 Charge Characteristics

The charging of the NiMH battery are generally similar to those of the sealed NiCd cells. The most common charging method is a constant current charge, the current is limited to avoid excessive rise of temperature. The voltage profiles of the NiMh and NiCd during charge process are rising as the battery accepts the charge. Characteristics of NiMh batteries define the need for charge control to terminate the charge, to prevent the battery from being overcharged or exposed to high temperatures. The main goal is to maximize battery life. The highest capacity of the battery would be achieved with the 150% charge input, but at expense of cycle life. The longest cycle life is attained with 120% charge input but with lower capacity due to the insufficient charge input. Some most broadly used methods for charge control are [1]:

- Timed charge
  Charge is terminated after a battery has been charged for a determined amount of time. The method should be used at low rates to avoid excessive overcharge, since the SOC prior to charging cannot always be determined. This procedure is often used as the final charging strategy additional to other charge termination methods to ensure complete recharge.

- Voltage Drop ($-\Delta V$)
  The voltage during charge is monitored and charge is terminated when the voltage begins to decrease. This method is difficult to implement for the NiMH cells since the peak voltage is not as prominent and may be absent in charge currents below 0.3C, particularly at elevated temperatures. The voltage signal sensing must be set as a trade off between terminating the charge when voltage drops, and not terminating the charge prematurely due to noise or voltage fluctuation.

- Voltage Plateau ($0\Delta V$)
  An alternate method is to terminate charging process when the voltage peaks and the slope is zero rather than waiting for voltage drop. The risk of overcharge is reduced.

- Temperature Cut-off
  Another technique for charge control is to monitor the temperature rise of the battery and to terminate the charging process when the battery has reached a temperature that indicates the beginning of overcharge. This point is difficult to determine, as it is strongly influenced by the ambient temperature, cell and battery design, charge rate and other factors. Usually, this method is used in combination with other charging termination methods.

- Delta Temperature Cut-off (ΔT)
  The technique measures the battery temperature rise above the ambient temperature and terminates charge when this rise exceeds a predetermined value. The cutoff value is dependant on several factors, including cell size, configuration and number of cells.

- Rate of Temperature Increase ($\Delta T/\Delta t$)
  The change in temperature with the time is monitored and charge is terminated when a predetermined incremental temperature rise is reached.

NiMH batteries are flexible and accept different types of charge methods. Several most commonly used charging methods are:

- Low Rate Charge (12 to 15h)
  Charging the battery at a constant current at about 0.1C rate with time limited charge termination. The charge control should be terminated after 150% capacity input.
- Quick Charge (4 to 5 h)
  The NiMH batteries can be safely recharged at higher rates, but charge control is required. The fully discharged battery can be charged at 0.3C rate for a charge time equivalent to 150% charge input (approx. 4.5-5h). Decrease in voltage should be sensed to ensure that charge is terminated early enough to minimize overcharge.
- Fast Charge (1h)
  To charge the NiMh battery in even shorter time is possible by charging the cells at constant current at the 0.5-1C rates. It is essential to terminate the charging early to avoid overcharge. With this method voltage decrease as well as temperature cut off can be used to terminate the charge. NiMH batteries are able to accept 60 to 80% charge within 15 minutes, after this point current must be reduced.
- Trickle Charge
  Several applications require the use of batteries that are maintained in fully charged condition.This can be achieved by trickle charging the NiMH cells, charging at a rate that replaces the capacity loss due to self-discharge.A trickle charge at a current between 0.03 and 0.05 C rates is recommended.
- Three-Step Charge Procedure
  The method provides the possibility to charge NiMH cell to fully charge without overcharge and exposure to high temperatures.
  1. Charge at 1C rate and terminate by $\Delta T/\Delta t$ or $-\Delta V$
  2. Follow by 0.1 C topping charge, terminate by timer after 1h of charge
  3. Maintenance charge of indefinite duration at current between 0.05 and 0.02C. Battery is protected by a thermal cutoff device.

3.2.3 Discharge Characteristics

The discharge characteristics of sealed NiMH batteries are very similar to those of sealed NiCd batteries. The OCV of both chemistries ranges from 1.25 to 1.35V, the nominal voltage is 1.2V and the typical end voltage is 1.0V. Typical discharge curves vary for cylindrical sealed NiMH cells under various constant current loads and temperatures. The capacity can be increased by continuing the discharge to the lower end voltages, particularly at the higher current drains rates and lower temperatures, where the voltage drops off more rapidly than at the lighter drain rates.

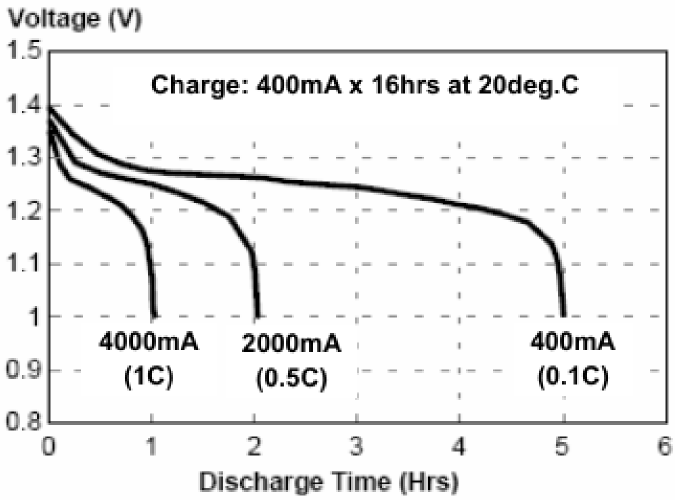
The discharge voltage profile of NiMH battery is considered "flat" and varies with the rate of discharge and temperature. As a fully charged battery is discharged the voltage begins at about 1.5V followed by sharp drop around 1.3V. The voltage remains between 1.3V to 1.2V for about 75% of the profile until a second sudden drop in voltage occurs as the useful capacity of the battery begins to deplete. With elevated discharge rates, the entire discharge profile is lowered by internal resistance. At high temperatures, the discharge profile is raised by an increase in potential (voltage) between electrodes.

The industry standard for the rated voltage of NiMH cell is 1.2V. This is the nominal voltage of a cell that is discharged at a rate of C/10 at a temperature of 25° C to an end voltage of 1.0V.

For technical applications and calculations, the nominal voltage of a battery pack provides a useful approximation of the average voltage throughout discharge. The nominal voltage can be simply calculated after the battery has been discharged.

A flat discharge profile is characteristic.

Figure 3.3.: NiMH Discharge profile @ different Discharge Rates [1]



Self-Discharge

The NiMH batteries like all batteries have a certain level of self discharge that occurs when battery is at rest. The factors contributing to self discharge include the energy used by the oxygen cycle at high state of charge. Longer term contribution to self discharge is caused by chemical ion shuttles which continuously discharge the cell over longer period of time. The rate of the self discharge is highly dependant on the temperature of the cell. Higher temperatures yield higher self discharge rates.

3.2.4 Temperature characteristics

The relationship between capacity of the NiMH cells and the discharge temperature is summarized in figure below.

Figure 3.4.: NiMH self discharge @ different storage temperatures [1]

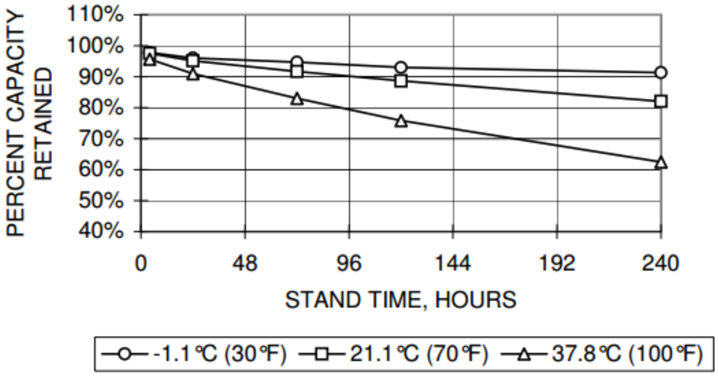
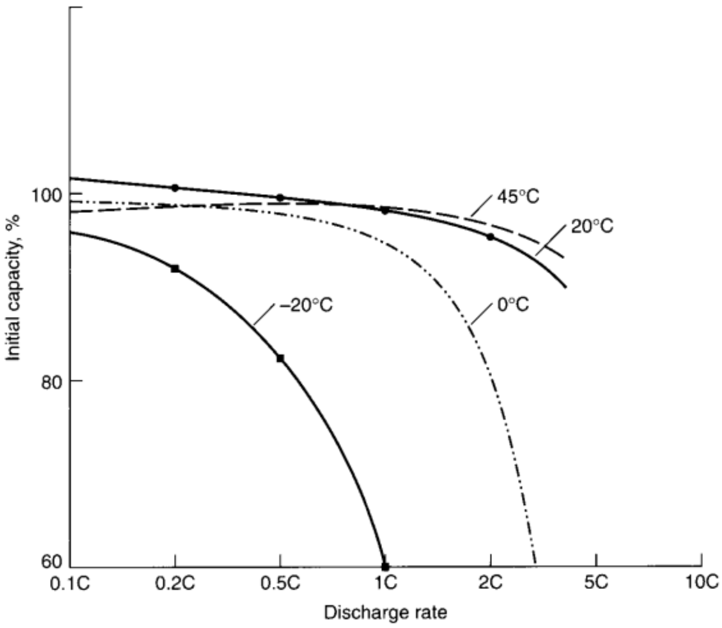


Figure 3.5.: NiMH discharge profiles @ different operational temperatures[1]



Typically, the best performance for NiMH batteries is obtained at the temperatures between 0 and 40°. Outside the range, the discharge characteristics are affected moderately at higher temperatures, and more significant at lower temperatures. High temperature charge efficiency is significant issue, since NiMH are broadly used in propulsion applications, e.g. electric and hybrid vehicles. The vehicles are intended to be used in the war climates, where vehicle range is strongly influenced by ambient temperature. The first generation of the NiMH batteries lost almost 50% of the rated capacity, when charged at 60°.

3.2.5 SOC Measurement

Similar to NiCd and LiIon batteries the SOC measurement of NiMH is usually based on the one or combination of the methods described in chapter 1.2.

3.2.6 Main Areas of Application

NiMH batteries are considered to be the most technically mature of the current battery technologies. Typical applications include consumer electronics, laptops, cell phones, EV and HEV just to name a few. NiMH cells are also used in industrial applications that require tough batteries such as power tools, railway applications and backup systems. In Europe NiMH is already finding application in replacing NiCd cells in standby lighting apparatus. NiMH cells have been used in several different implementations of electric vehicles including Toyota Prius, Honda Insigth and the Ford Escape. Interest in NiMH for hybrid vehicles is expanding to heavy duty vehicles and buses due to its potential for the high power and cycle life.

The NiMH consumer cell was developed to replace sealed NiCd cells used in portable electronics. With 30% to 50% better energy density the NiMH cell quickly caught on for applications such as cell phones and laptops.

The broadest application areas of the NiMH are the low cost consumer applications, however LiIon cells are taking over this market, e.g. electric razors, toothbrushes, cameras, mobile phones, automotive batteries.

3.2.7 Memory Effect

A voltage drop and loss of capacity may occur when a sealed NiMH battery is partially discharged and recharged repetitively without the benefit of a full discharge. After an initial full discharge and charge the battery is partially discharged and recharged for a number of cycles. During cycling, the discharge voltage and the capacity drop gradually. On a subsequent full discharge the discharge voltage is depressed compared to the original full discharge.

This phenomenon is known as **memory effect**, as battery seems to remember lower capacity. The battery can be restored to full capacity within a few full charge-discharge cycles. The voltage drop occurs because only a portion of the active material are discharged and recharged during shallow or partial discharging. The extent of the memory effect and capacity loss depends on the depth of discharge and can be avoided or minimized by discharging to an appropriate voltage. The effect is also dependent on the discharge rate. The depth of discharge is less at higher rates. This increases capacity loss.

While the memory effect result into reduced battery performance, the actual voltage depression and capacity loss are only a small fraction of battery's total capacity.

3.2.8 Advantages Disadvantages of NiMH batteries

Advantage	Disadvantage
Higher energy density and specific energy compared to lead-acid and nickel-cadmium	Higher cost than lead-acid
Good high-temperature and high-rate capability	Lower specific energy and specific power compared to Li-Ion
Good charge retention	Decreased performance at low temperatures
Rapid recharge capability	Memory effect
Long shelf life	
Sealed maintenance-free design	

3.3 NiCd

Sealed NiCd (nickel-cadmium) cells and batteries are available in several construction forms. The most common types are cylindrical shaped batteries.

3.3.1 Chemistry

In the uncharged condition the positive electrode of a nickel-cadmium cell is nickelous hydroxide, the negative - cadmium hydroxide. In the charged condition the positive electrode is nickel hydroxide, the negative - metallic cadmium. The electrolyte is potassium hydroxide. The average operating voltage of the cell under normal discharge conditions is about 1.2 volts. The charging chemical reaction of the NiCd system can be considered as depicted below:

$$2NiOOH + Cd + 2H_2O \rightarrow 2Ni(OH)_2 + Cd(OH)_2 \tag{3.4}$$

The discharge reaction can be summed up as follows:

$$2Ni(OH)_2 + Cd(OH)_2 \rightarrow 2NiOOH + Cd + 2H_2O \tag{3.5}$$

3.3.2 Charge Characteristics

Sealed NiCd batteries are usually charged using constant current method. The 0.1C rate can be used to fully charge battery up to 140% over 12 to 16h. At this rate, the risk of the overcharging is minimized, although the most NiCd cells can be also charged with C/100 to C/3 charging rate without harm. At higher rates it is crucial to avoid overcharging the battery. There are a number of different methods for charging sealed NiCd batteries. The most commonly used method is quasi-constant current charge at a relatively low rate. Fast charging methods are becoming more and more popular in order to reduce the time required for charging. A control circuit is needed when charging these at high rates to cut off the charge or reduce the charge current at the completion of charge. Similar to NiMh charging, following charging methods exist [1]:

- **Standard Method**
  This is the most common and simple method, using relatively inexpensive circuit, controlling the charge current by inserting resistance between the DC power supply and battery. The battery is charged at a constant current at a low (C/10). The rate limits generation of oxygen and temperature rise. The battery is then charge to about 140 to 150 % capacity.

- **Timer Control**
  The timer is used to cut off the charge or reduce the charge current to the trickle charge level. The electronics used are relatively inexpensive, however this method is not suitable for applications where the battery is usually fully discharged before charging. An additional thermal cut-off should be used when charged at rates higher than C/5.

- **Temperature detection**
  A sensor is used to detect the temperature rise of the battery and terminate the charge, usually with threshold set at 45°C. It is important to place sensor correctly.

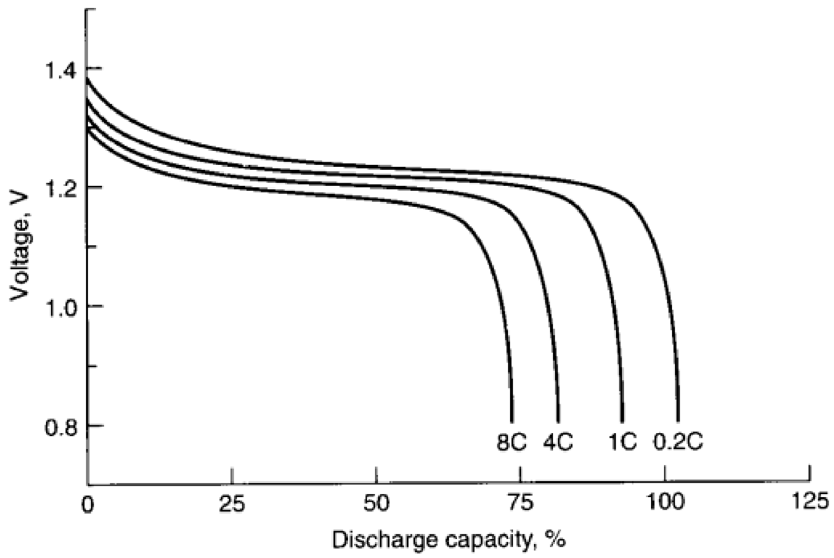
- **Negative Delta V (**$-\Delta$V)
  One of the preferred charge control methods. The drop in voltage of the battery is detected after the battery voltage has reached its peak during the charge. The trigger signal can be used to terminate the charge or reduce the charge current to trickle charge. The method provide complete charge independent from ambient temperature or residual capacity from the previous charge. A value of 10 to 20 mV per cell is usually used for control. The method is not suitable for charging below the 0.5C as the delta is too low to be detectable.

- **Trickle and Float Charge**
  Trickle charge are used either for standby power applications where the battery is on continual charge to maintain it in a state of full charge (compensating full discharge) until connected to the load, or as supplementary charge after the termination of rapid charging. Charging is at the 0.02 to 0.05 C rate, depending on the frequency and depth of discharge.

3.3.3 Discharge Characteristics

Typical discharge curves for cylindrical NiCd battery at 20°C at various discharge loads is shown in figure below. Permanent failure of the NiCd cells may occur form two cases: short-circuiting and loss of electrolyte.

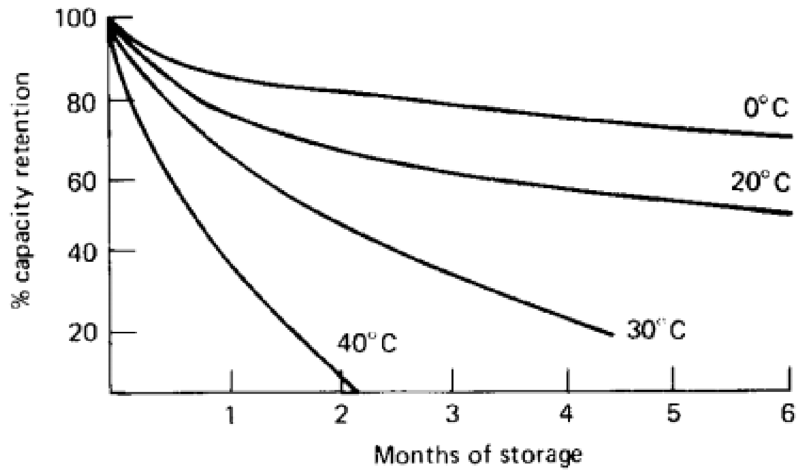
Figure 3.6.: NiCd discharge characteristics @ different discharge rates[1]



Self-Discharge

Sealed NiCd batteries lose capacity during storage. The rate of self-discharge is a function of storage temperature and battery construction. NiCd cells can be stored in charge or a discharge condition. Except for extended storage at high temperatures, they can be restored to full capacity after storage by recharging. Figure below sums au general shelf life (capacity or charge retention) at several temperatures for typical NiCd cells.

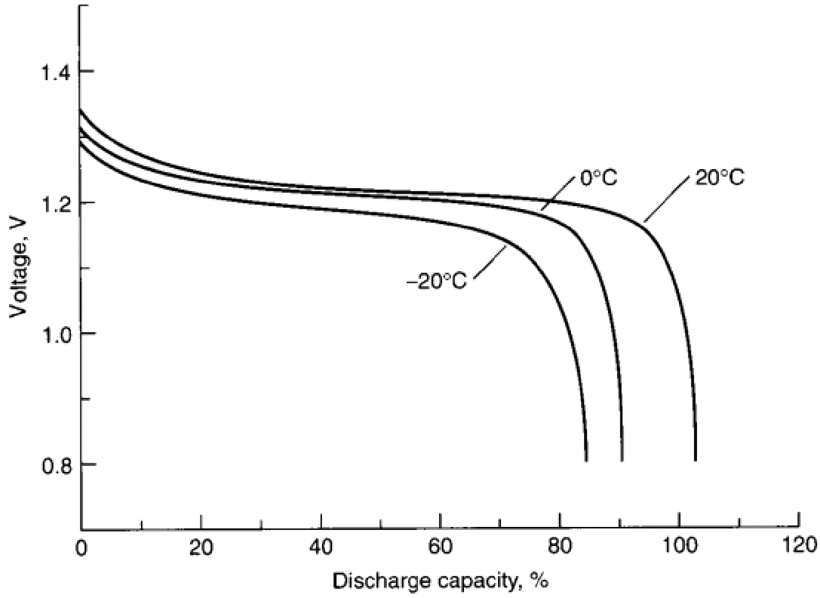
Figure 3.7.: NiCd self-discharge characteristics @ different storage temperatures[1]



3.3.4 Temperature characteristics

Sealed NiCd batteries are capable to perform over a wide temperature range of -20 and +30°C, although usable performance can be obtained beyond this range. The low-temperature performance, at high-rates is generally better than that of lead-acid battery. The reduction in performance at low temperatures occurs due to an increase in internal resistance. At high temperatures, the loss can be due to a depressed operating voltage or to self-discharge. Figure below shows the effect of temperature and discharge rate on the capacity of a sealed NiCd battery. This data is general for standard batteries. For more specific data manufacturer data should be used.

Figure 3.8.: NiCd discharge characteristics @ different operational temperatures[1]



3.3.5 SOC Measurement

SOC estimation is usually based on one of the methods described in chapter 1.2.

3.3.6 Memory Effect

NiCd batteries may suffer voltage depression and reversible loss of capacity when cycled repetitively on shallow discharge (discharge terminated before its full capacity is delivered) and recharge curves. The discharge profile may show two steps and the battery may not deliver the fully capacity to the original cut off voltage. The original capacity may be restored with a few full discharge-charge reconditioning cycles.

The extent of the memory effect depends on the depth of discharge and can be avoided or minimized by the selection of an appropriate cut off voltage. Too high cut off voltage, e.g 1.16V terminates discharge prematurely. Less significant memory effect occurs if discharge is terminated between 1.16 and 1.10V. The extent of the effect is further dependant on the discharge rate. Discharging the cells below 1.1V is not advisable.

3.3.7 Main areas of application

Because of their reliability, low maintenance, rugged design and long life, NiCd are used in variety of applications, in the areas such as rail road, industry, telecommunications and hybrid vehicles. Most of these applications are of an industrial nature. The NiCd batteries were originally developed for traction applications, approx. 40% of all industrial NiCd batteries are used in train lightning and air-conditioning for rail cars, emergency and standby systems, such as emergency brakes, door openers, diesel-engine cranking, rail road signalling as well as standby power in rail stations and traffic systems. Further application areas of NiCd batteries include: motorised equipment, power tools, two way radios, electric razors, medical instrumentation and toys.

3.3.8 Advantages Disadvantages of NiCd batteries

Advantage	Disadvantage
Long cycle life	Moderate initial cost
Broad temperature range of operation	Degrades at high temperature
Long shelf life	Need for protective circuitry
Low self-discharge rate	Capacity loss and potential for thermal runaway when overcharged
Rapid charge capability	Possible venting and possible thermal runaway when crushed
High-rate and high-power discharge capability	May become unsafe if rapidly charged at low temperatures (<0° C)
High coloumbic and energy efficiency	
High specific energy and energy density	
No memory effect	
Many possible chemistries offer design flexibility	
Can be made in aluminium plastic cases as "pouch" or polymer cells	

3.4 Li-Ion

3.4.1 Chemistry

Lithium-ion battery exists in several different variations depending on the electrode and electrolyte materials. Generally, for the electrodes lithium storage compounds are used. The positive electrode material is typically a metal oxide with a layered structure, such as lithium cobalt oxide ($LiCoO_2$) or a metal having a tunnelled structure such as lithium manganese oxide ($LiMn_2O_4$) on an aluminium current collector. The negative electrode material is usually a graphic carbon which is also layered on an copper current collector. The separator is a fine porous polypropylene or polypropylene film. The two main types of electrolytes used are liquid and gel electrolytes. Liquid electrolytes are solutions of a lithium salt in one or more organic solvents. A gel electrolyte is an ionically conductive material, where a salt and a solvent are dissolved with polymer. Most of the current Li-ion electrolytes utilize lithium hexafluorophostphate $LiPF_6$, with high conductivity and safety properties as main advantages.

As the battery is cycled lithium ions ($Li+$) exchange between the positive and negative electrodes. The first introduced and the majority of the current available Li Ion batteries utilize $LiCoO_2$ as positive electrode material. Several other positive electrodes have been introduced, such as $LiFePO_4$, $LiMn_2O_4$, $Li(NiMnCo)O_4$ and $Li(NiCoAl)O_2$. The materials have different characteristics and offer each different advantages, such as high-rate capability, low cost, high thermal stability, long cycle life and/or high capacity.

The chemical reactions at both electrodes result in potential difference. Nominal OCV of the single cell at full charge is 4.2 V. OCV at full discharge is 2.5 V.

Cell construction of the Li-ion cells is varies depending on the particular design of the cell manufacturers, however two main types cylindrical and prismatic cells. Sheet-like cathode and anode terminals are wound together in a spiral shape. Between the cathode and anode a polymer separator film is placed to interrupt reaction in case of cell temperature exceeds the normal. To ensure the safety cells often have safety mechanism, such as circuit breaker, rupture disk and positive temperature coefficient device. Cylindrical and prismatic cells have similar construction, except for prismatic cell having flat mandrel instead of cylindrical mandrel.

Lithium polymer cells are often emphasized as an own type of battery chemistry. However, those are an sub category of the Li-ion cells. Originally, such cells had a polymer or gel as electrolyte. Cells which are marketed as "polymer" today are lithium-ion cells in a flexible aluminized polymer package, often referred as pouch.

3.4.2 Charge Characteristics

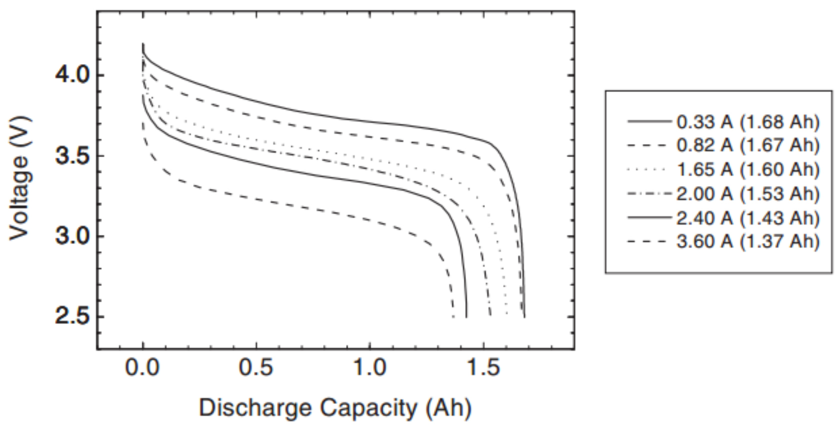
Li-Ion cells require a dedicated constant voltage/current limited charging algorithm for safe and reliable operation. There exist several types of charging algorithms. The common chargers utilize CC/CV constant current / constant voltage charging process. The charger limits the current until the voltage across the cell reaches the 4.20V, after that point the charger changes to constant voltage operation and the current begins to decrease down to the specified cut off current or to specified charging time. The most of the charge is achieved in the constant current part of the charging process. The constant voltage part achieves the last percent of the charge but takes much longer. The maximum charging current of the cells is limited for the most of cells to 1C, however depending on the cell chemistry charging with higher currents is possible. The cut off voltage of the common cells is specified by the manufacturer as 4.10V or 4.20V.

3.4.3 Discharge Characteristics

During the discharge process the voltage of the charged Li ion cell drops from the initial 4.20V. Unlike another cell chemistries the cell voltage exhibits less of the plateau with a rapid voltage reduction in voltage towards the end of the discharge. The discharge is terminated by te end of discharge voltage, which is usually 3.0 V (although the end of discharge voltage can be lower, it is not recommended to discharge lower than that voltage to avoid deep discharge).

The rate capability and capacity of LiIon batteries are dependent on their design and varies considerable between manufacturers. Discharge curves for 18650 type $LiCoO_2$ batteries discharged at rates from 0.33A to 3.6A at 21° C are shown below. The discharge curves have a flat voltage profile with average voltage at the C rate of 3.65 V.

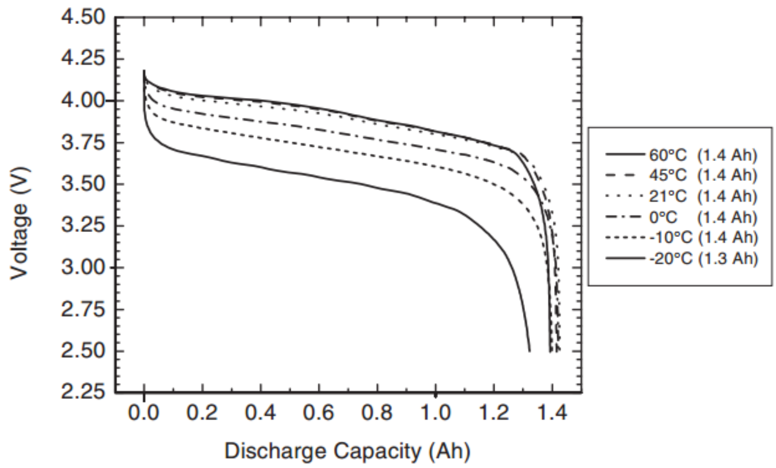
Figure 3.9.: Li-Ion discharge characteristics @ different discharge rates[1]



3.4.4 Temperature characteristics

The voltage and capacity on discharge at the C/5 rate for 18650 type $LiMn_2O_4$ battery can be found in the figure below.

Figure 3.10.: Li-Ion discharge characteristics @ different operational temperatures[1]



3.4.5 SOC Measurement

The SOC of the Li-ion battery can not be measured directly it has to be derived from the primary characteristics of the battery such as cell voltage, cell temperature, cell internal resistance, etc. Depending on the primary characteristic used for the SOC estimation different methods exist.

- OCV based
  Li ion cells provide characteristic voltage curve while discharged. Measuring the voltage of the cell directly can provide the information about the remaining battery capacity. This is the easiest and at the same time the most inaccurate method. OCV must be measured precisely to derive SOC, since the voltage curve of the Li-ion cells is very flat during the discharge process till the characteristic "knee" in the discharge curve occurs. After the voltage drops rapidly it is already deep discharged. OCV has to be measured in the "equillibrium" state of the cell. For the OCV method to provide precise measurement a short pulse load has to be applied followed by hours to stabilize the cell voltage and to achieve the "equilibrium" state. In the most applications such conditions are not provided. The main advantages of the method include no full discharge required, no correction for the self discharge required, accuracy for the small load currents. For higher currents the cell voltage drops significantly due to the internal resistance of the battery.

- Coulomb counting based
  The method utilizes current measurement. Starting at the fully charged state the current provided to load is tracked. The main advantages of the method are: the precise direct measurement of the current is possible, the measurement is not influenced by the voltage distortion under load.

$$SOC = \frac{Q_{rem}}{Q_{max}} = SOC_0 + \frac{\Delta Q}{Q_{max}} \tag{3.6}$$

- Internal resistance based

Internal resistance of the Li ion battery is divided into internal impedance and resistance.

3.4.6 Main areas of application

LiIon are the most utilized cell chemistry with such areas of application as electric vehicles, **pendelec!**, consumer products, industrial applications, medical equipment, etc.

3.4.7 Advantages Disadvantages of LiIon Batteries

Advantage	Disadvantage
Sealed cells; no maintenance needed	Low energy density
Long cycle life	Higher cost than lead-acid batteries
Broad temperature range of operation	Memory effect
Long shelf life	Explosion hazard due to hydrogen
Excellent long-term storage	Temperature controlled charging system required to extend life
Low maintenance	
Flat discharge profile	

3.4.8 LiPo

There is no common definition of polymer LiIon cell. Originally, such cells had a polymer or gel electrolyte. Cells marketed today as polymer LiIon cells are no more than a regular LiIon cells in a flexible alumnized package, thus the more correct term to be used is **pouch cells**.

The Li polymer differs from other battery systems in the type of electrolyte used. This electrolyte resembles a plastic like film that does‘t conduct electricity but allows to exchange of ions. The polymer electrolyte replaces the traditional porous separator. The dry Li polymer suffers from poor conductivity, for this reason most of the commercial cells are hybrid. Some gelled electrolyte is added to the dry polymer. The correct term for this type is Li Ion Polymer. With gelled electrolyte added the LiPo cells have very similar characteristics as LiIon cells.

For the present, there is no cost advantage in using the LiIon polymer battery. The major reason for switching to the Li-ion polymer is form factor. It allows wafer-thin geometries, a style that is demanded by the highly competitive mobile phone industry. At the present time, the pouch cell is more expensive to manufacture than the cylindrical architecture and the reliability has not been fully proven. The energy density and load current are slightly lower than that of conventional cell designs.

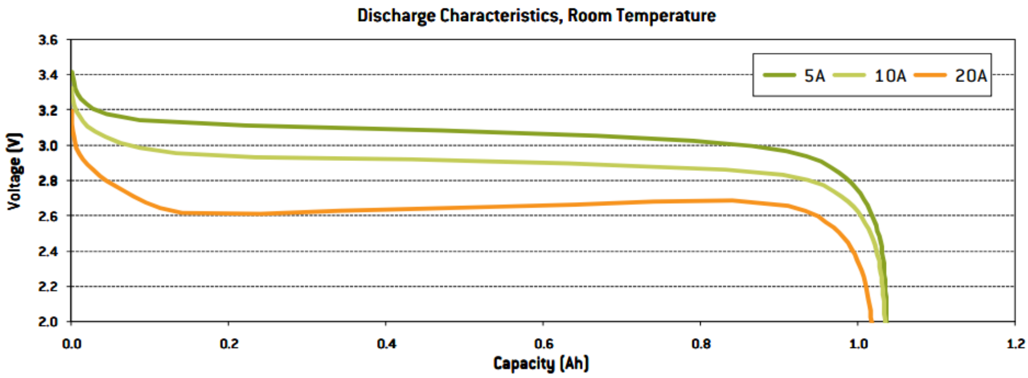
The Li-ion polymer offers little or no energy gain over conventional Li ion systems; neither do the slim profile Li-ion systems meet the cycle life of the rugged 18560 cell. The cost-to-energy ration increases as the cell size decreases in thickness. Cost increases in the multiple of three to four compared to the 18650 cell are common on exotic slim battery designs.

If space permitted, the 18650 cell offers the most economical choice, both in terms of energy per weight and longevity. Applications for this cell are mobile computing and video cameras. Slimming down means thinner batteries. This, in turn, will make the cost of the portable power more expensive.

3.4.9 LiFePo4

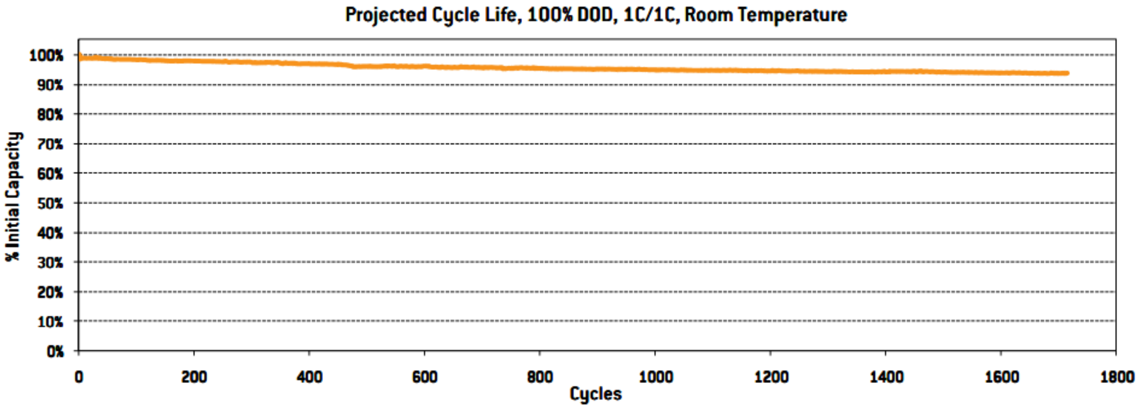
Lithium Iron Phosphate batteries differ form standard lithium batteries in cathode material. This is made with nano-scale phosphate material. The key benefits of the LiFePo4 are high current rating, long life cycle life, good thermal stability and enhanced saefty. Li-phosphate are more tolerant to full charge and less stressed than other Li-ion systems if opposed with high voltage. Graphite power cells have impressive power capabilities and provide long cycle life. Additionally they are most thermally stable of all the Li-Ion cells. The drawback of the LiFePO4 cells is their relatively low specific energy density. The cells provide only 3.3V nominal capacity but are able to provide higher continuous discharge rates. The recommended cut off voltage is 2V at 25 °. The discharge characteristics can be found in the picture below.

Figure 3.11.: LiFePO4 discharge characteristics @ different discharge rates[9]



Since LiFePO4 cells are able to provide high currents in the short time, their usage is advantageous in the applications where the load occurs in short bursts. E.g. A1423 Systems worked together with Formula 1 team to produce extremely high power LiFePO4 cells for racetrack. The cells were able to provide Figure below shows the capacity versus cycle number for APR18650 cell. The cell provides almost 95 % capacity after 1000 cycles.

Figure 3.12.: LiFePO4 cycle life characteristics[9]



4 Battery Characteristics Measurement

This chapter provides measurement data for the selected cells described in the 2.4. Concurrently the measurement data is compared to the manufacturer provided battery characteristics.

4.1 Test Specification

To provide more or less comparable data among the same chemistry cells, the specification for the charge and discharge tests should be provided. Even though the same chemistry cells have similar characteristics, each manufacturer provides the rated and nominal capacity at specified charge and discharge rates. To test the provided data, the tests will be performed at the charge and discharge rates provided by the manufacturer. The batteries will be tested against standard rated discharge capacity. In cases if no data provided the typical charge and discharge rates for respective chemistry will be used. Following characteristics of the battery chemistries will be recorded:

- Charge Curve
- Discharge Curve
- Battery Nominal Capacity
- Internal Resistance

Test conditions for the all specified below:

- Environmental Conditions
  Unless otherwise specified, all tests stated in this document are performed at temperature of 25+/-5$°C$.
- Measuring Equipment

  1. Battery Charger
     Graupner Ultra Duo Plus 50 for LiPo/LiIon/LiFe/NiMh/Nicd with LogView Studio visualisation software, providing the charging curve and direct internal resistance measurement data
  2. Electronic Load
     Elektro-Automatic DC electronic Load EA-EL3160-60 rated with max. 160V, 60A, 400W. Providing discharge data and indirect internal resistance measurement data (pulsed).

4.2 Li-Ion

4.2.1 Samsung ICR18650 22P

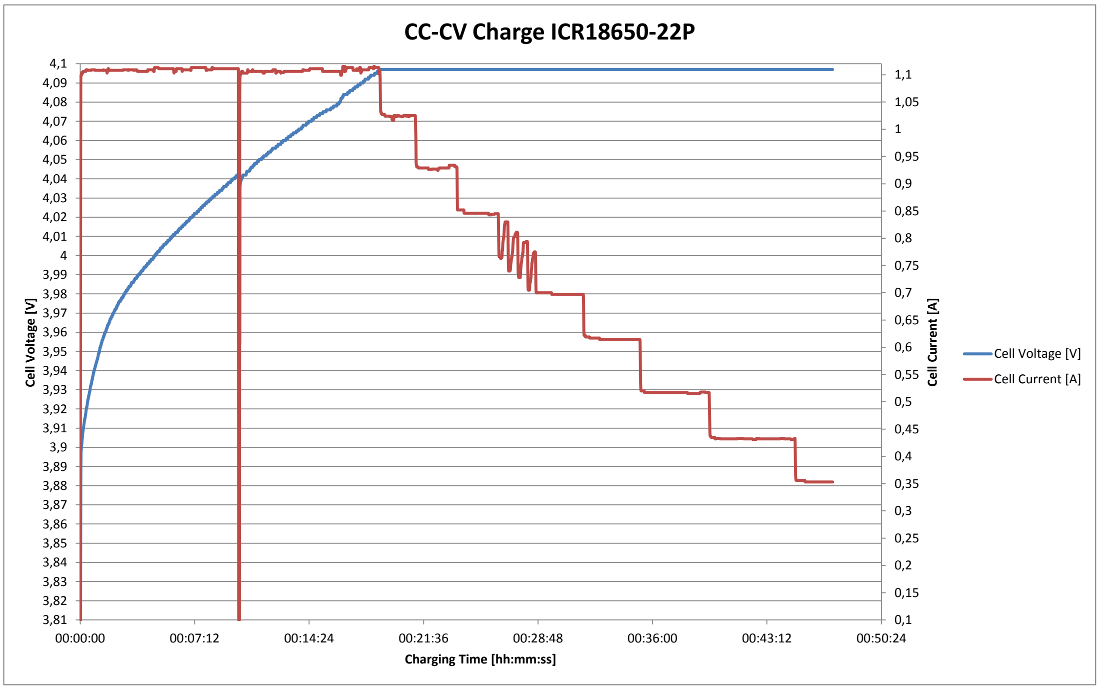
The specification for the charge and discharge rates includes [10]:

- Standard Charge
  Charging the cell CC-CV mode with 1075 mA and constant voltage 4.2V at 25$^{\circ}C$ and 41mA cut-off in CV mode.
- Nominal discharge capacity
  The standard discharge capacity is the initial discharge capacity of the cell, which is measured with discharge current of 2150mA with 2.75V cut-off at 25$^{\circ}C$ within 1 hour after the standard charge.

The nominal discharge capacity is specified at the above characteristics with approx. $2050mAh$.

The charge curve (voltage and current profile) and the battery output capacity can be found below.

Figure 4.1.: ICR18650 22P Charge Curve



The discharge curve (discharge capacity and voltage profile) with standard discharge current can be found below.

Figure 4.2.: ICR18650 22P Discharge Curve

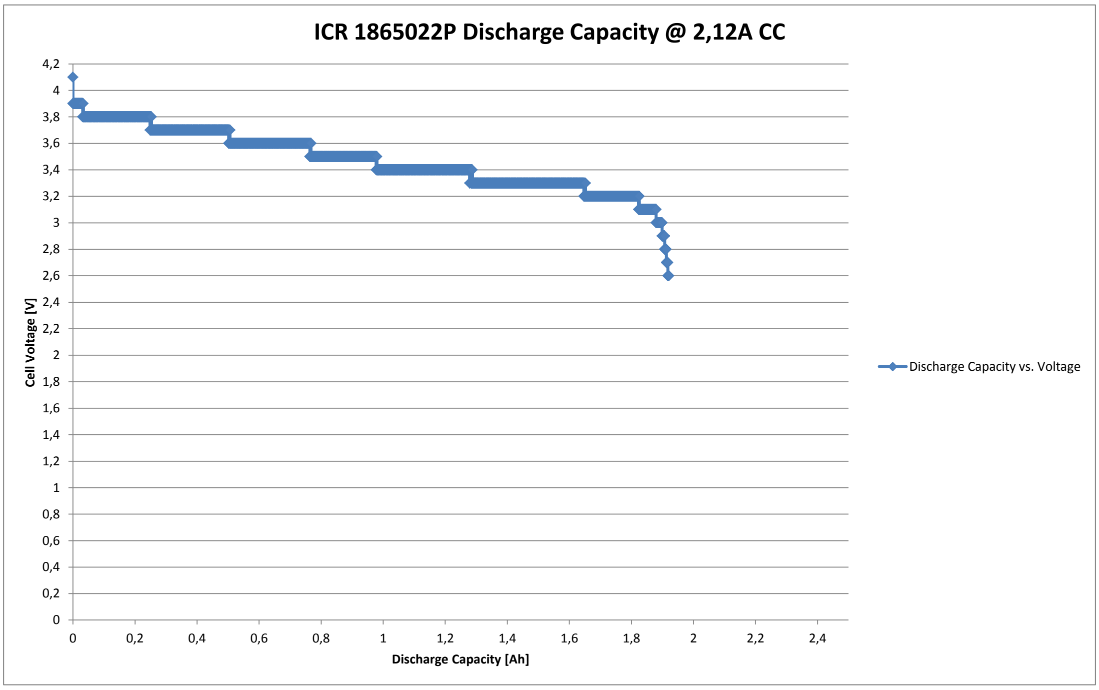


Table 4.1.: Measured Data @ 2,12 A

Discharge up to Voltage [V]	Discharge Capacity [Ah]
3,9	0,031
3,7	0,510
3,5	0,991
3,3	1,667
3,1	1,897
2,9	1,925
2,7	1,935
2,5	1,940

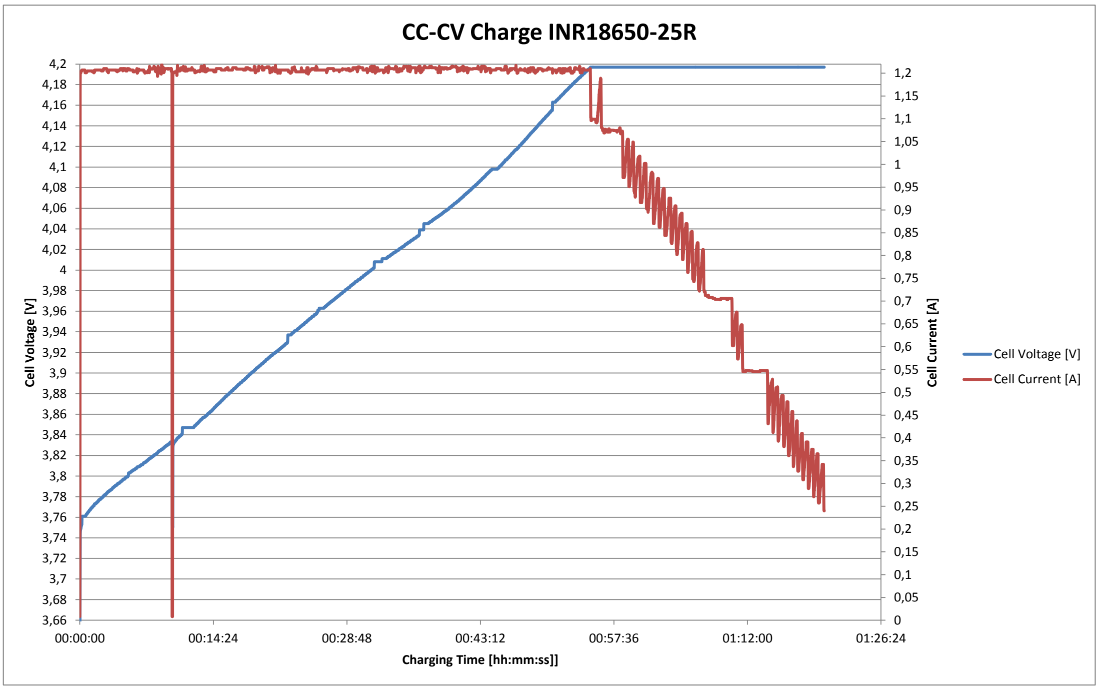
4.2.2 Samsung INR18650 25R

The specification for the charge and discharge rates includes [11]:

- Standard Charge
  Charging the cell in CC-CV mode with 1250mA and constant voltage 4.2V at 25$°C$ and 125mA cut-off in CV mode
- Nominal discharge capacity
  The standard discharge capacity is the initial discharge capacity of the cell, which is measured with discharge current of 10A with 2.5V cut-off at 25$°C$ within 1 hour after the standard charge.

The nominal discharge capacity is specified at the above characteristics with approx. $2450mAh$.

Figure 4.3.: INR18650 Charge Curve



The discharge curve (discharge capacity and voltage profile) with standard discharge current can be found below.

Figure 4.4.: INR18650 Discharge Curve

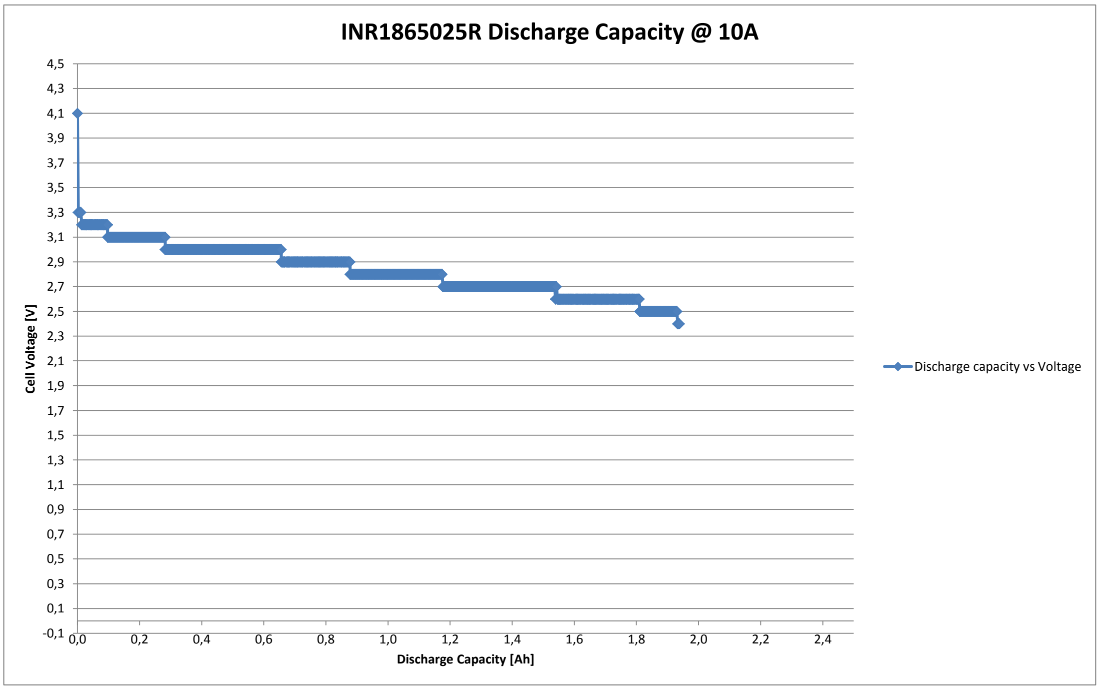


Table 4.2.: Measured Data @ 10A

Discharge up to Voltage [V]	Discharge Capacity [Ah]
3,3	0,01
3,1	0,28
3,5	0,991
2,9	0,880
2,7	1,540
2,5	1,930

4.2.3 Panasonic NCR18650A

The specification for the charge and discharge rates includes [12]:

- Standard Charge
  Charging the cell in CC-CV mode with 1475 mA and constant voltage 4.2V at 25$°C$ and 59mA cut-off in CV mode.

- Nominal discharge capacity
  The standard discharge capacity is the initial discharge capacity of the cell, which is measured with discharge current of 3100mA (1C) with 2.5V cut-off at 25$°C$ within 1 hour after the standard charge.

The nominal discharge capacity is specified at the above characteristics with approx. $3100mAh$.

Figure 4.5.: NCR18650A Charge Curve

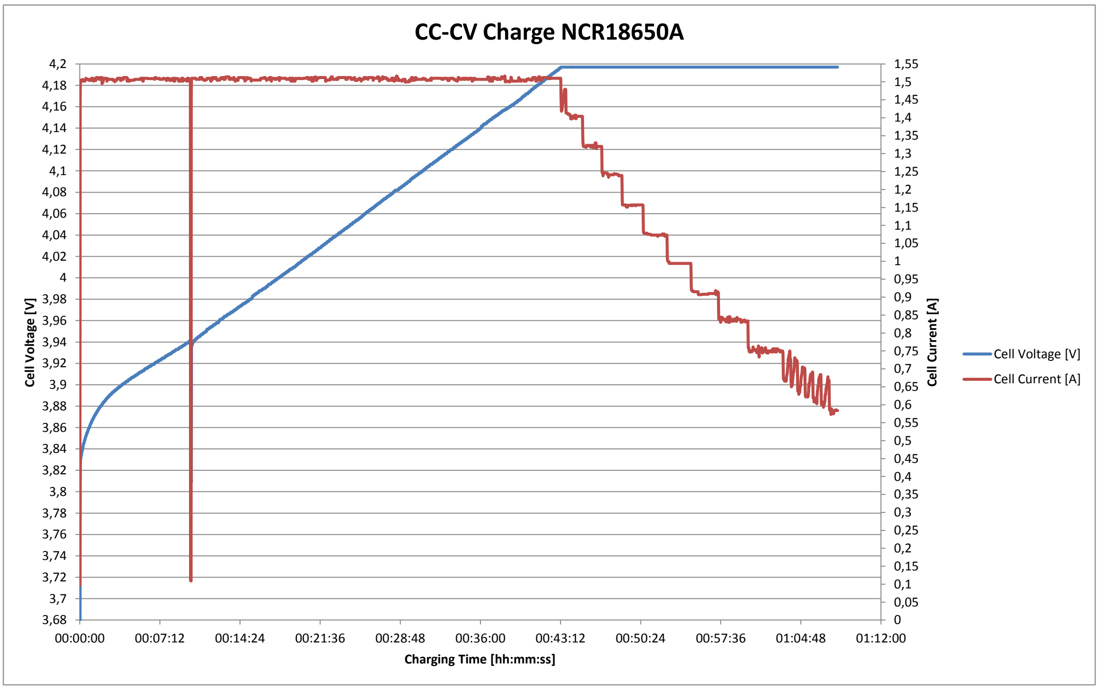


Figure 4.6.: NCR18650A Discharge Curve

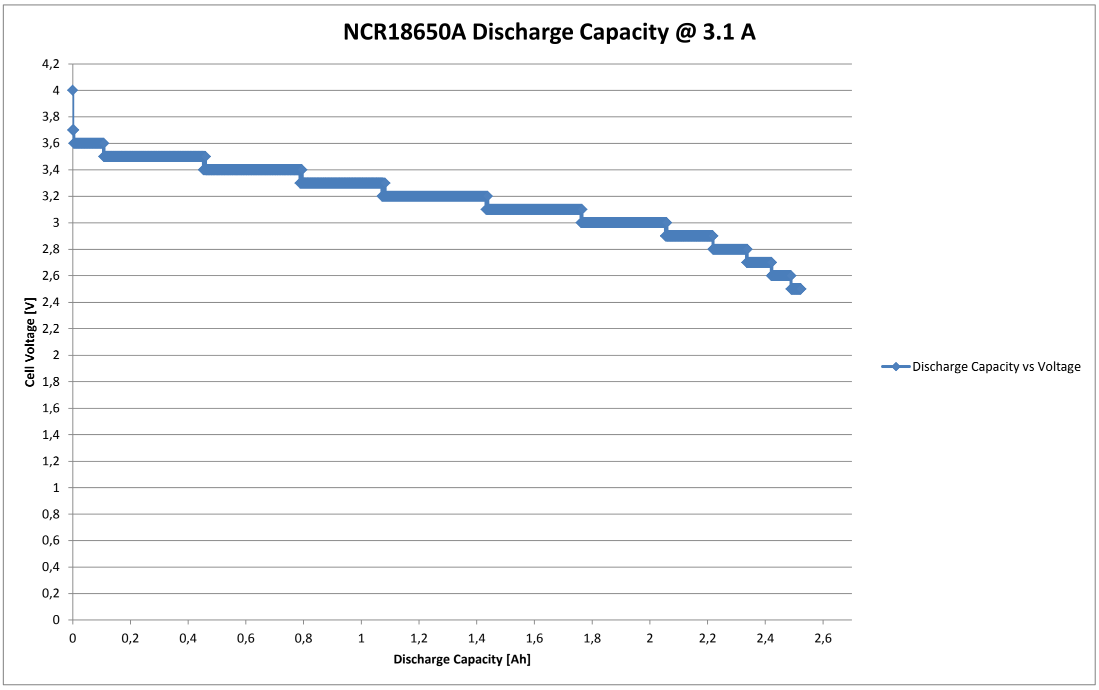


Table 4.3.: Measured Data @ 3,1A

Discharge up to Voltage [V]	Discharge Capacity [Ah]
3,7	0,003
3,5	0,473
3,3	1,103
3,1	1,795
2,9	2,253
2,7	2,457
2,5	2,560

4.2.4 Sony US18650V3

The specification for the charge and discharge rates includes [13]:

- Standard Charge
  Charging the cell in CC-CV mode with 2150mA and constant voltage 4.2V at 25$^{\circ}C$ for 2.5 hours.

- Nominal discharge capacity
  The standard discharge capacity is the initial discharge capacity of the cell, which is measured with discharge current of 2100 (1C) with 2.5V cut-off at 25$^{\circ}C$ within 1 hour after the standard charge.

The nominal discharge capacity is specified at the above characteristics with approx. $2137mAh$.

Figure 4.7.: US18650V3 Charge Curve

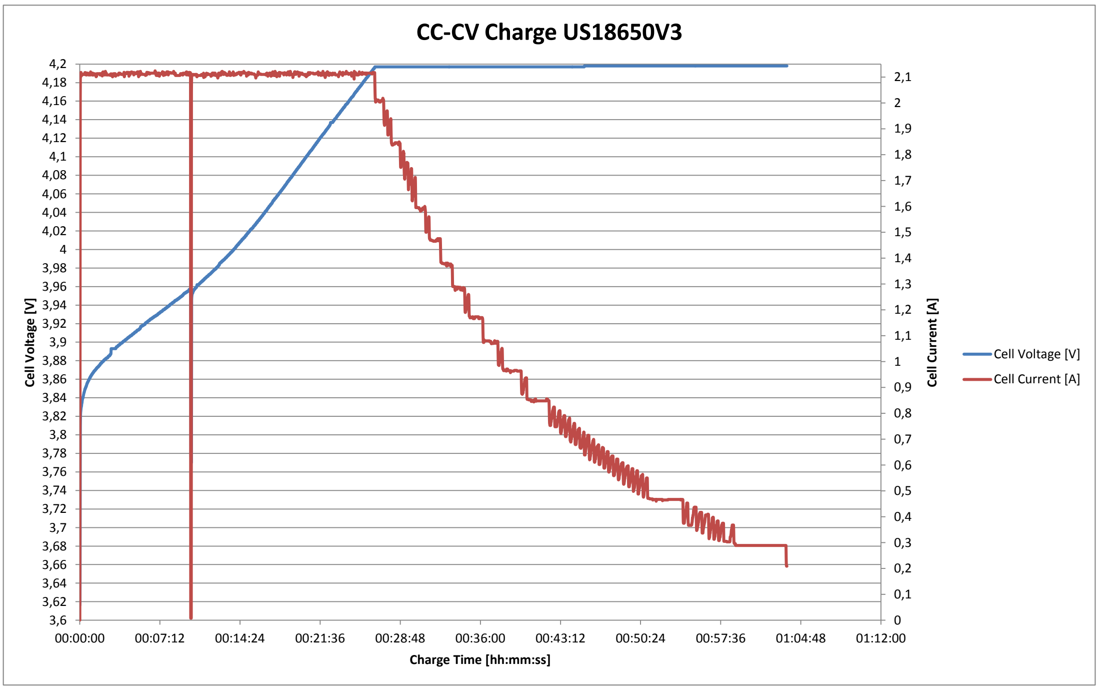


Figure 4.8.: US18650V3 Discharge Curve

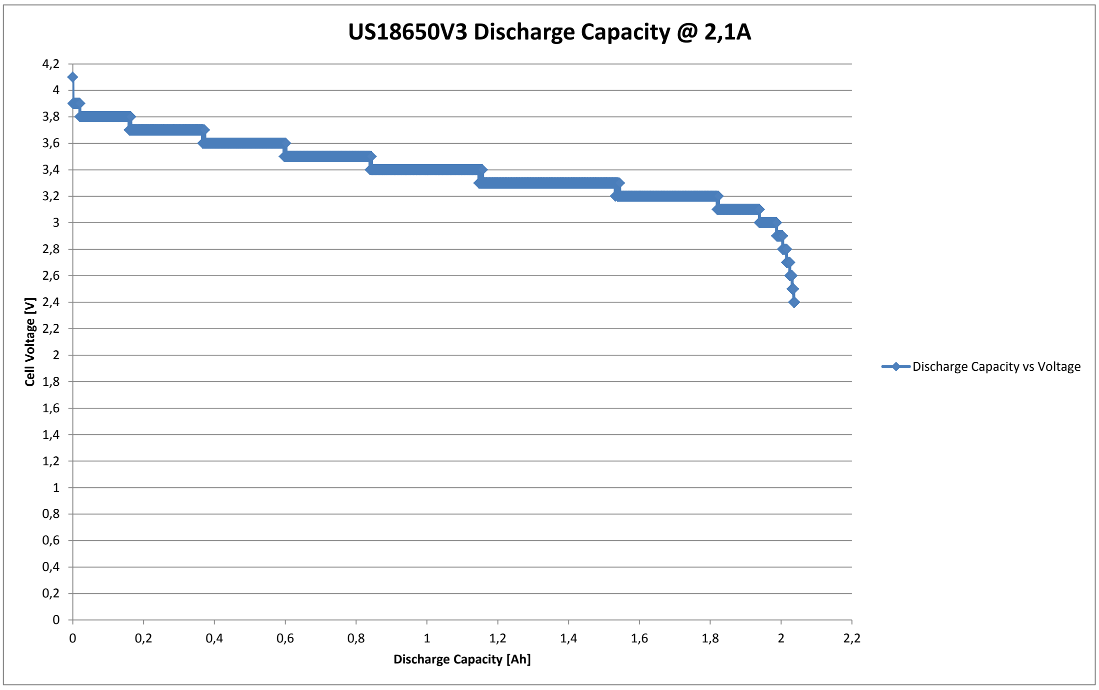


Table 4.4.: Measured Data @ 2,15A

Discharge up to Voltage [V]	Discharge Capacity [Ah]
3,9	0,019
3,7	0,337
3,5	0,850
3,3	1,555
3,1	1,954
2,9	2,021
2,7	2,042
2,5	2,053

4.3 LiFePo4

4.3.1 A123 APR18650MA1

The specification for the charge and discharge rates includes [9]:

- Standard Charge
  Charging the cell CC-CV mode with 1500mA and constant voltage 3.6V at 25$^{\circ}C$ for 45 minutes.

- Nominal discharge capacity
  The standard discharge capacity is the initial discharge capacity of the cell, which is measured with discharge current of 10000mA with 2V cut-off at 25$^{\circ}C$ within 1 hour after the standard charge.

The nominal discharge capacity is specified at the above characteristics with approx. $1100mAh$.

Figure 4.9.: APR18650MA1 Charge Curve

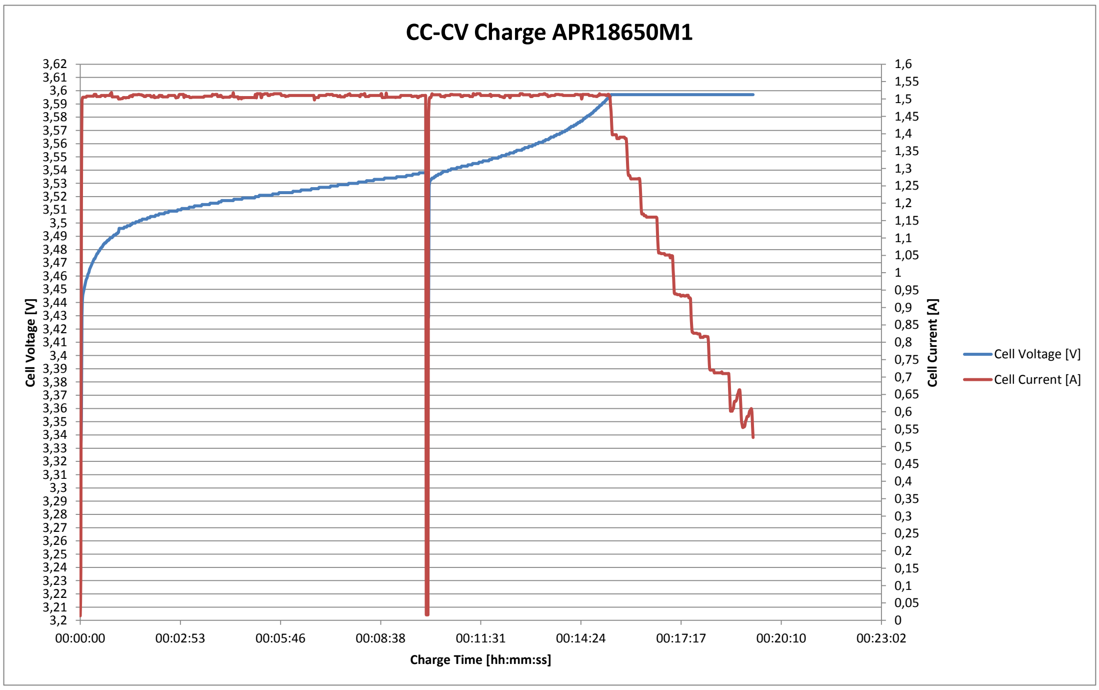


Figure 4.10.: APR18650MA1 Discharge Curve

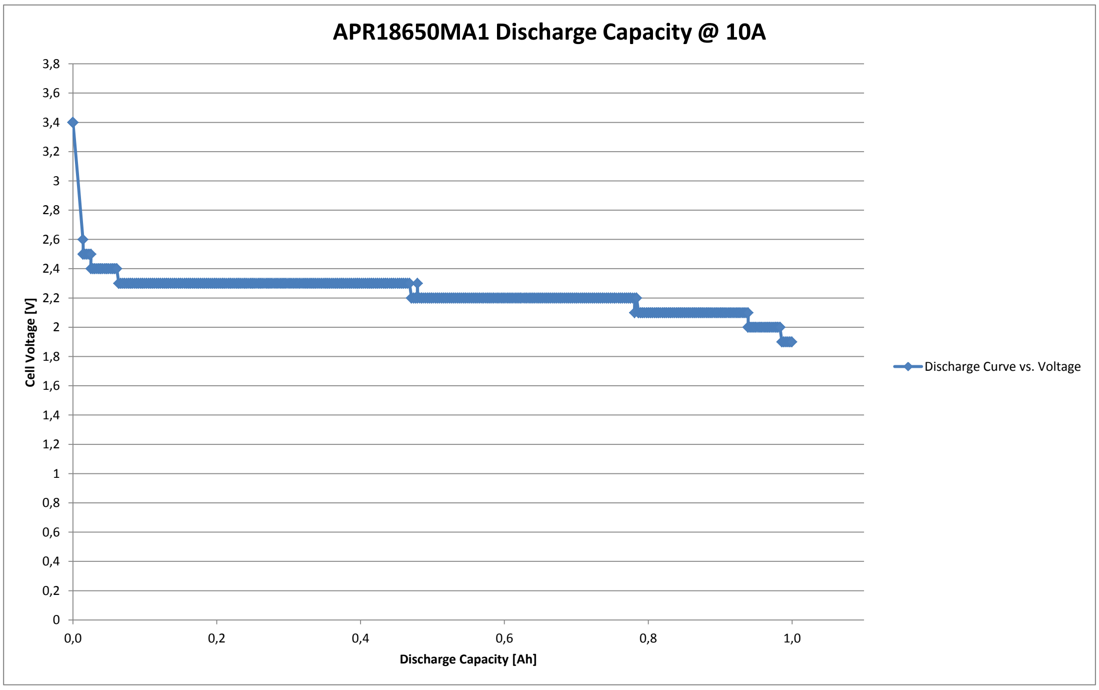


Table 4.5.: Measured Data @ 10A

Discharge up to Voltage [V]	**Discharge Capacity [Ah]**
2,5	0,012
2,3	0,472
2,1	0,957
1,9	1,021

4.4 NiCd

4.4.1 Panasonic N-1250SCRL

The specification for the charge and discharge rates includes [14]:

- Standard Charge
  Charging the cell CC mode with 1900mA at 25$^{\circ}C$ with delta peak detection $\Delta 10mV$.
- Nominal discharge capacity
  The standard discharge capacity is the initial discharge capacity of the cell, which is measured with discharge current of 2400mA (2C) with 1V cut-off at 25$^{\circ}C$ within 1 hour after the standard charge.

The nominal discharge capacity is specified at the above characteristics with approx. $1200mAh$.

Figure 4.11.: N-1250SCRL Charge Curve

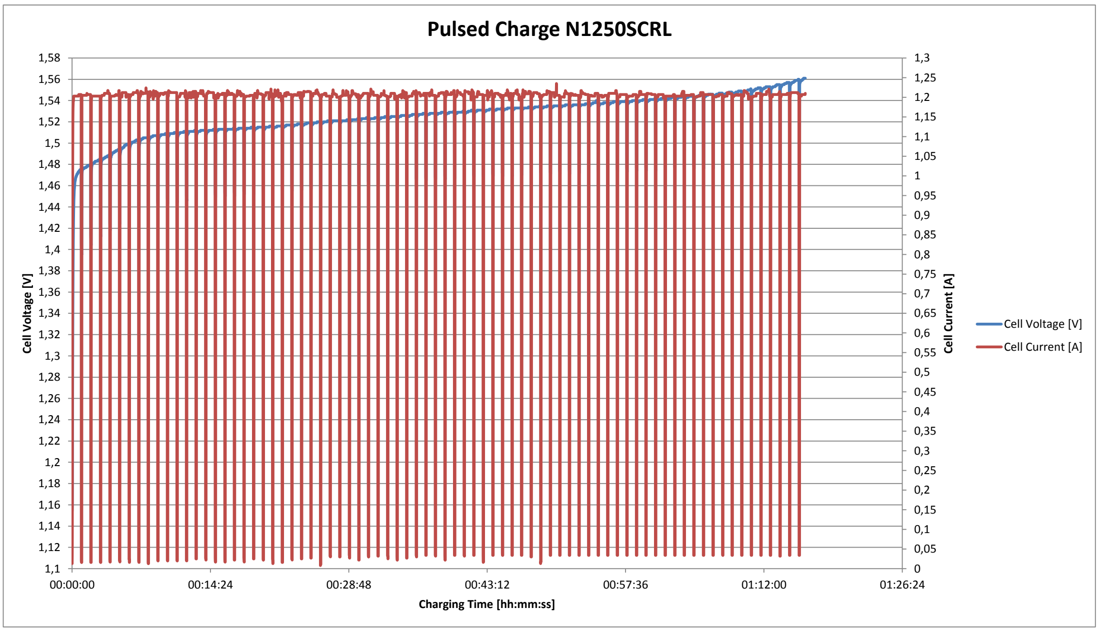


Figure 4.12.: N-1250SCRL Discharge Curve

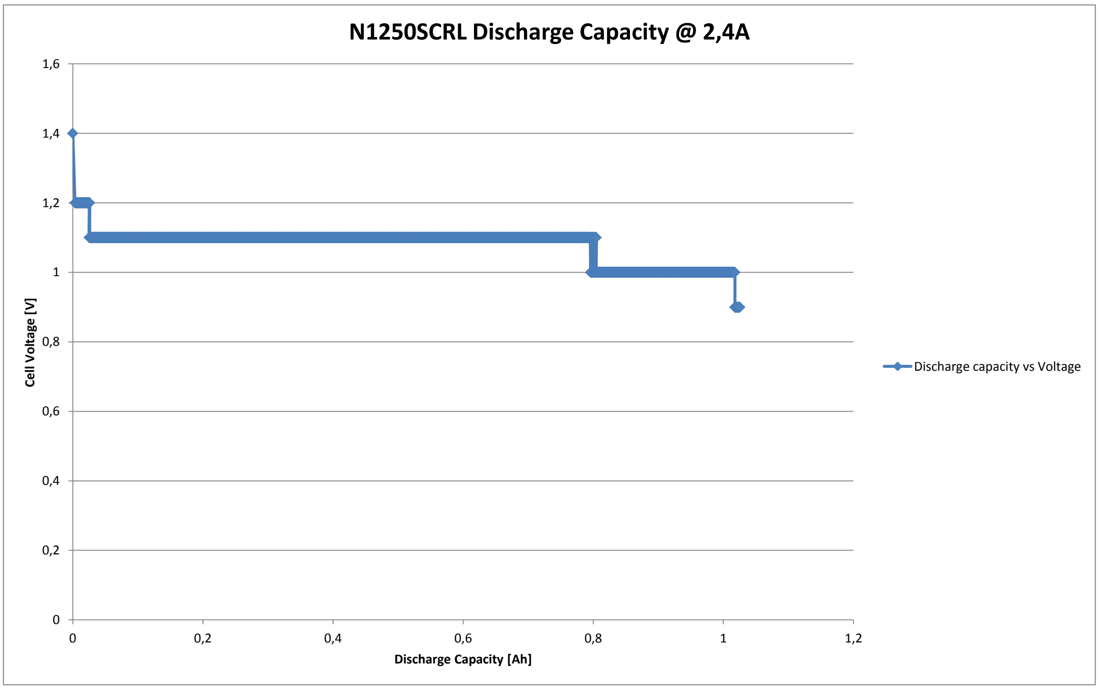


Table 4.6.: Measured Data @2,4A

Discharge up to Voltage [V]	Discharge Capacity [Ah]
1,2	0,022
1	1,027

4.4.2 Panasonic KR-1800SCE

The specification for the charge and discharge rates includes [15]:

- Standard Charge
  Charging the cell CC mode with 2700mA at 25$°C$ with delta peak detection $\Delta 10mV$.
- Nominal discharge capacity
  The standard discharge capacity is the initial discharge capacity of the cell, which is measured with discharge current of 3600mA (2C) with 1V cut-off at 25$°C$ within 1 hour after the standard charge.

The nominal discharge capacity is specified at the above characteristics with approx. $1800mAh$.

Figure 4.13.: KR-1800SCE Charge Curve

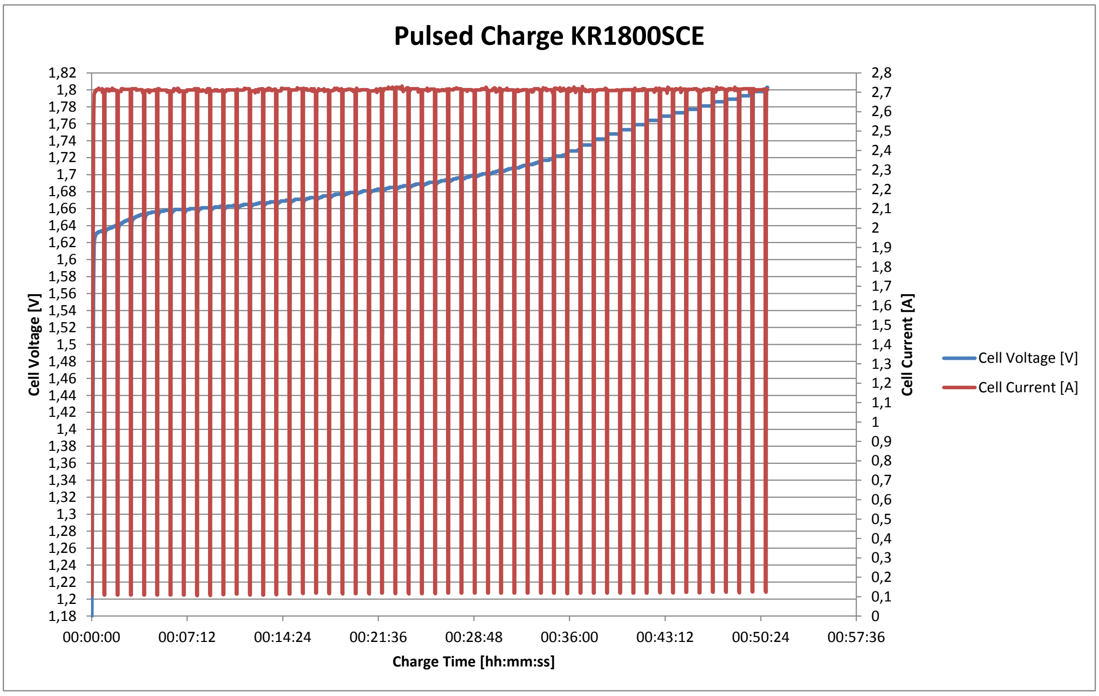


Figure 4.14.: KR-1800SCE Discharge Curve

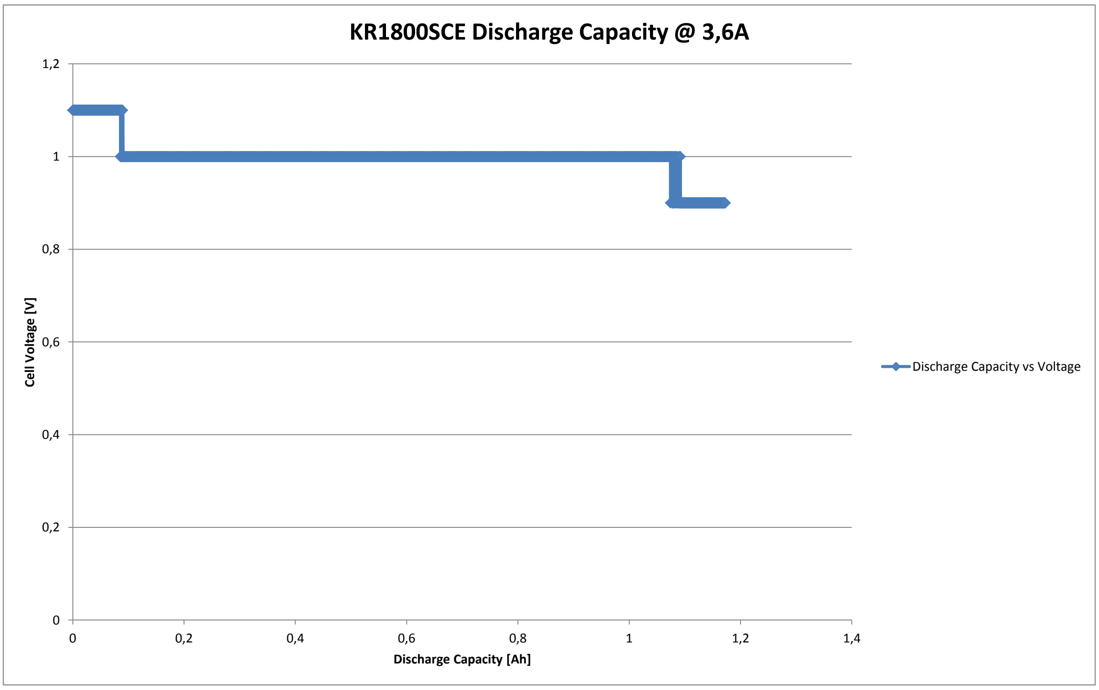


Table 4.7.: Measured Data @3,6A

Discharge up to Voltage [V]	Discharge Capacity [Ah]
1,2	0,001
1	1,15

4.5 NiMh

4.5.1 Emmerich 255003

The specification for the charge and discharge rates includes [16]:

- Standard Charge
  Charging the cell CC mode with 4000mA at 25$°C$ for approx. 1 hour with delta peak detection $\Delta 10mV$.

- Nominal discharge capacity
  The standard discharge capacity is the initial discharge capacity of the cell, which is measured with discharge current of 4000mA (1C) with 1V cut-off at 25$°C$ within 1 hour after the standard charge.

The nominal discharge capacity is specified at the above characteristics with approx. $4000mAh$.

Figure 4.15.: Emmerich 255003 Charge Curve

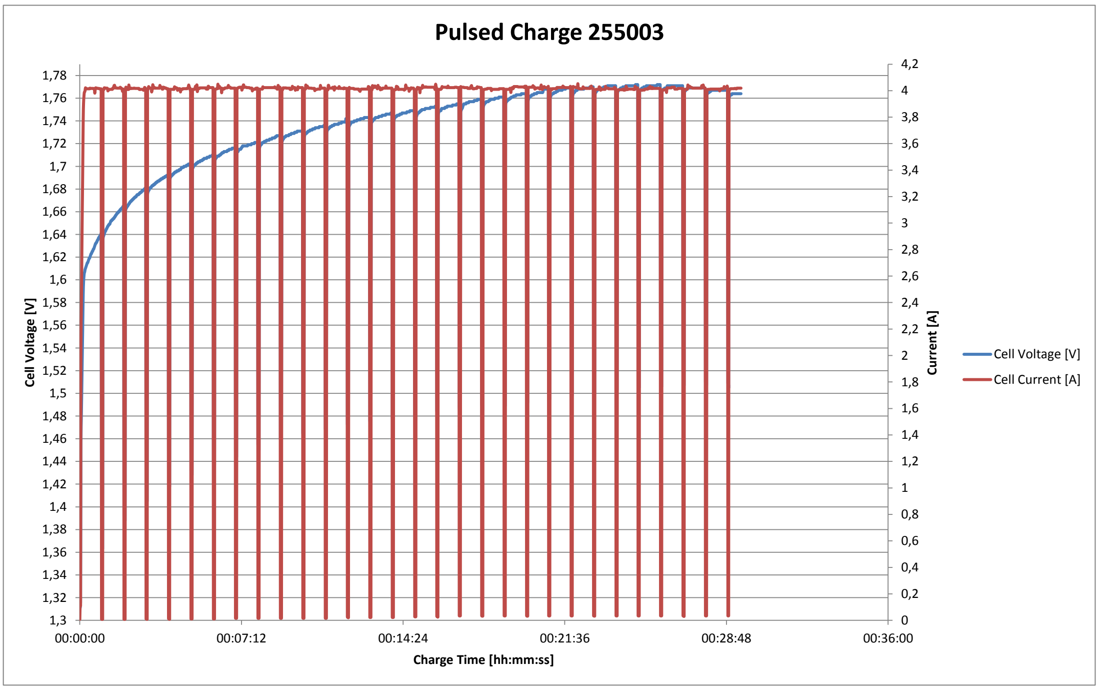


Figure 4.16.: Emmerich 255003 Discharge Curve

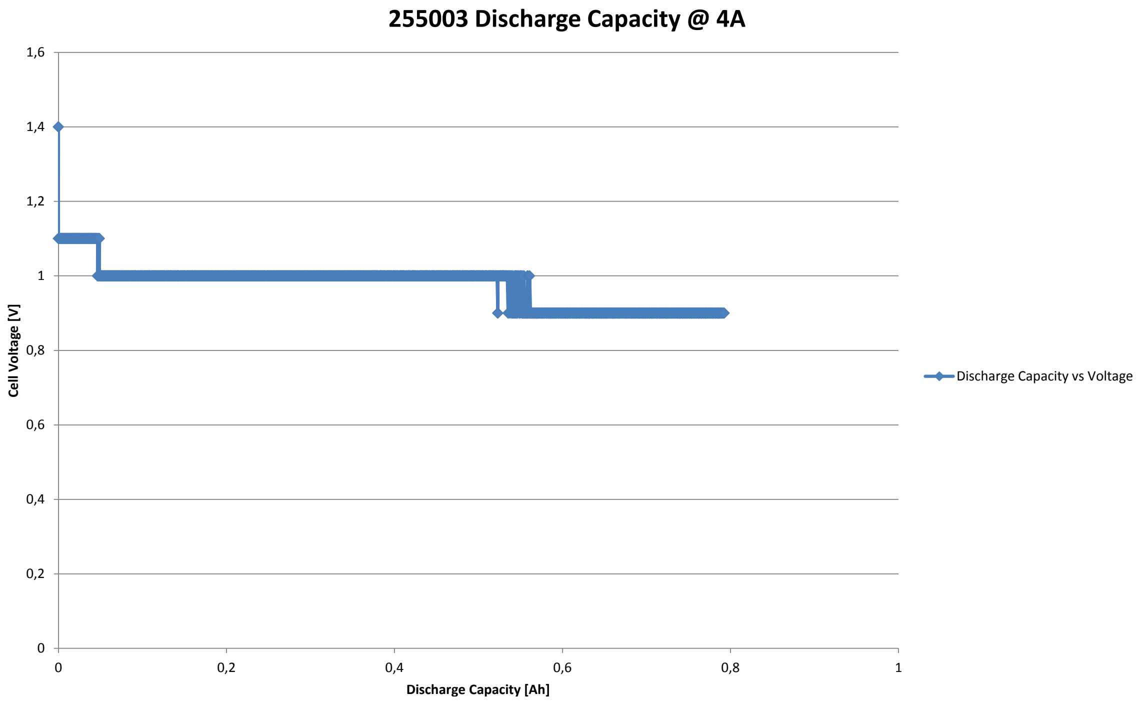


Table 4.8.: Measured Data @4A

Discharge up to Voltage [V]	Discharge Capacity [Ah]
1,2	0,001
1	0,568

4.5.2 Panasonic HHR-260SCP/FT

The specification for the charge and discharge rates includes [17]:

- Standard Charge
  Charging the cell CC mode with 2600mA at 25$°C$ for approx. 1 hour with delta peak detection $\Delta 10mV$.
- Nominal discharge capacity
  The standard discharge capacity is the initial discharge capacity of the cell, which is measured with discharge current of 10A with 1V cut-off at 25$°C$ within 1 hour after the standard charge.

The nominal discharge capacity is specified at the above characteristics with approx. $2600mAh$.

Figure 4.17.: HHR-260SCP/FT Charge Curve

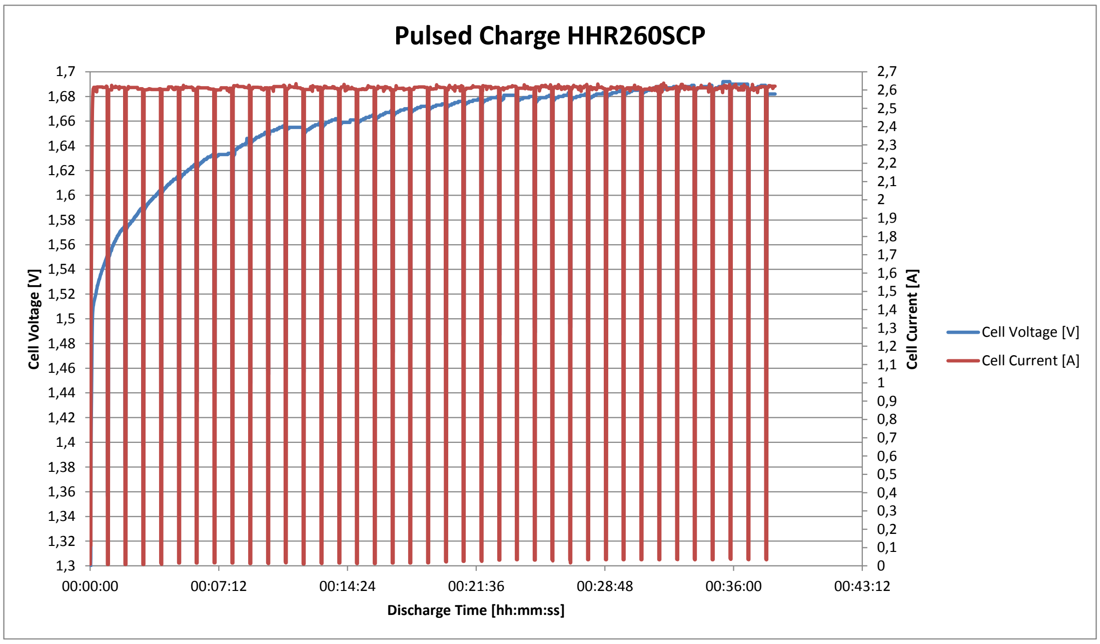


Figure 4.18.: HHR-260SCP/FT Discharge Curve

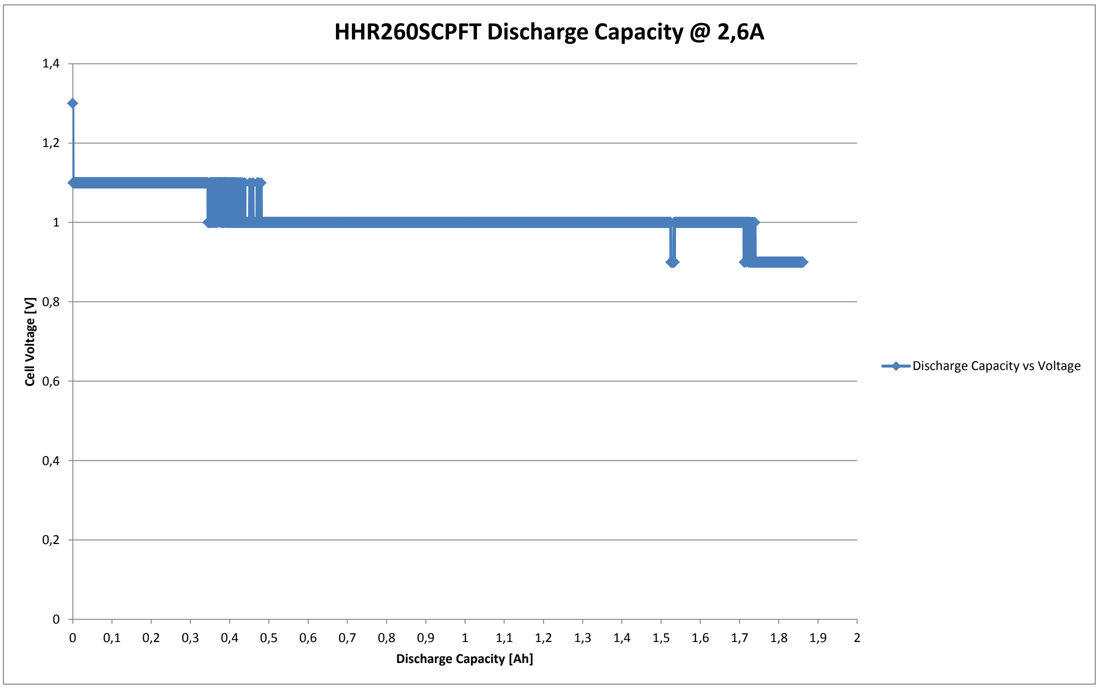


Table 4.9.: Measured Data @2,6A

Discharge up to Voltage [V]	Discharge Capacity [Ah]
1,2	0,001
1	1,789

4.6 VRLA

4.6.1 Condrad Energy HYSS613

The specification for the charge and discharge rates includes [18]:

- Standard Charge
  Charging the cell CC mode with 120mA at 20$^{\circ}C$ for approx. 4-6 hours.
- Nominal discharge capacity
  The standard discharge capacity is the initial discharge capacity of the cell, which is measured with discharge current of 780mA with 5,2V cut-off at 20$^{\circ}C$.

The nominal discharge capacity is specified at the above characteristics with approx. $1200mAh$.

Figure 4.19.: HYSS613 Discharge Curve

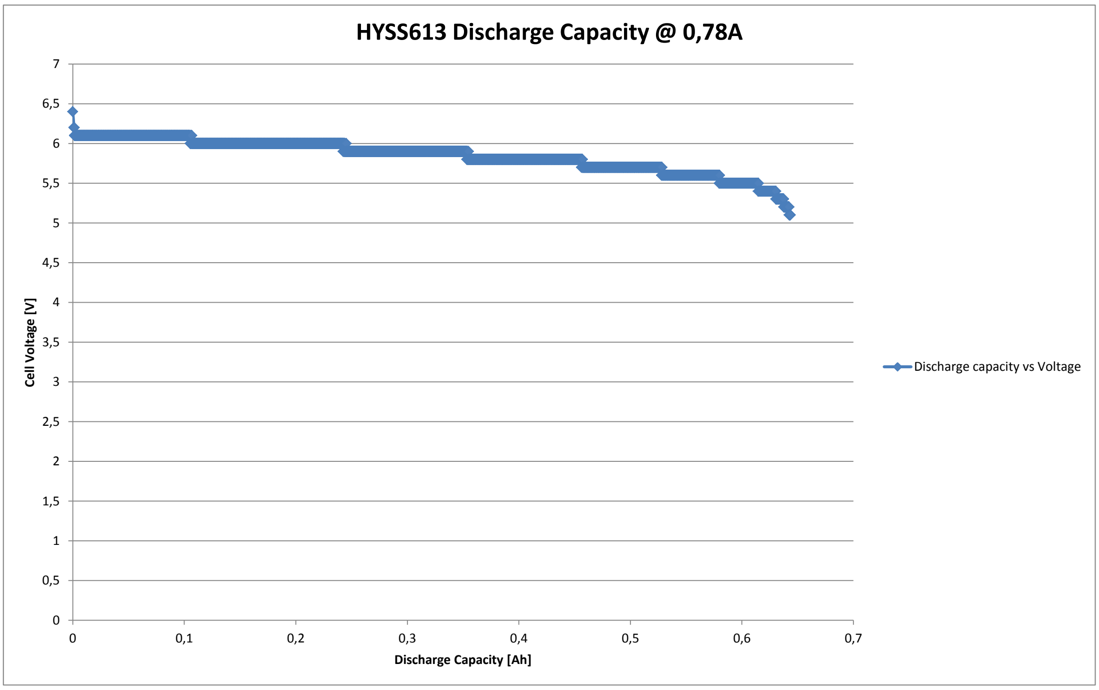


Table 4.10.: Measured Data @0,78A

Discharge up to Voltage [V]	Discharge Capacity [Ah]
6,2	0,001
6,0	0,251
5,8	0,464
5,6	0,587
5,4	0,639
5,2	0,651

Table 4.11.: Measurement Data @1,2A

Discharge up to Voltage [V]	Discharge Capacity [Ah]
12,2	0,001
11,6	0,157
11	0,352
10,4	0,439
10	0,455

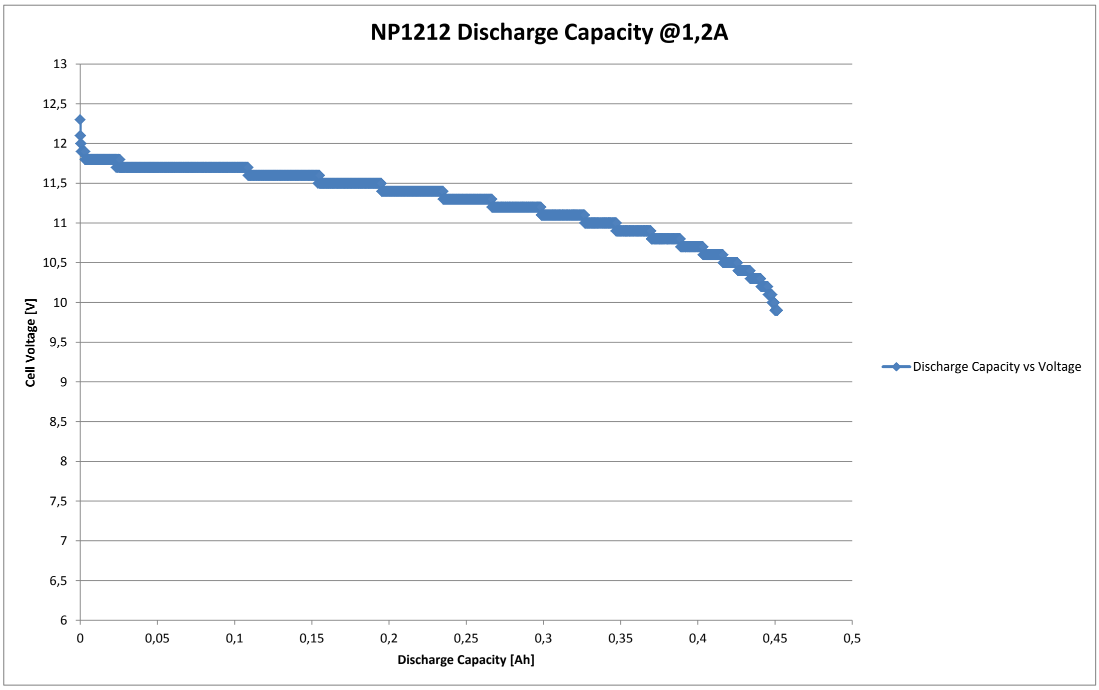
4.6.2 Yuasa NP1.2-12

The specification for the charge and discharge rates includes [18]:

- Standard Charge
  Charging the cell CC mode with 120mA at 20$°C$ for approx. 24 hours.
- Nominal discharge capacity
  The standard discharge capacity is the initial discharge capacity of the cell, which is measured with discharge current of 780mA with 10V cut-off at 20$°C$.

The nominal discharge capacity is specified at the above characteristics with approx. $1200mAh$.

Figure 4.20.: Yuasa NP1.2-12 Discharge Curve



5 Li-Ion Cell Comparison

For better understanding of the common Li-Ion cells, several measurements of the cell at different discharge rates has been performed. The common discharge rates for those tests should provide a basis for comparison among the chosen cells at different loads. The specified discharge rates are not dependant on the particular battery capacity, and are chosen as follows:

- Discharge at 2A
- Discharge at 3A
- Discharge at 5A

The measured discharge curves for each cell can be found below.

Figure 5.1.: Li-Ion Cells Discharge Curves Comparison @ 2A Rate

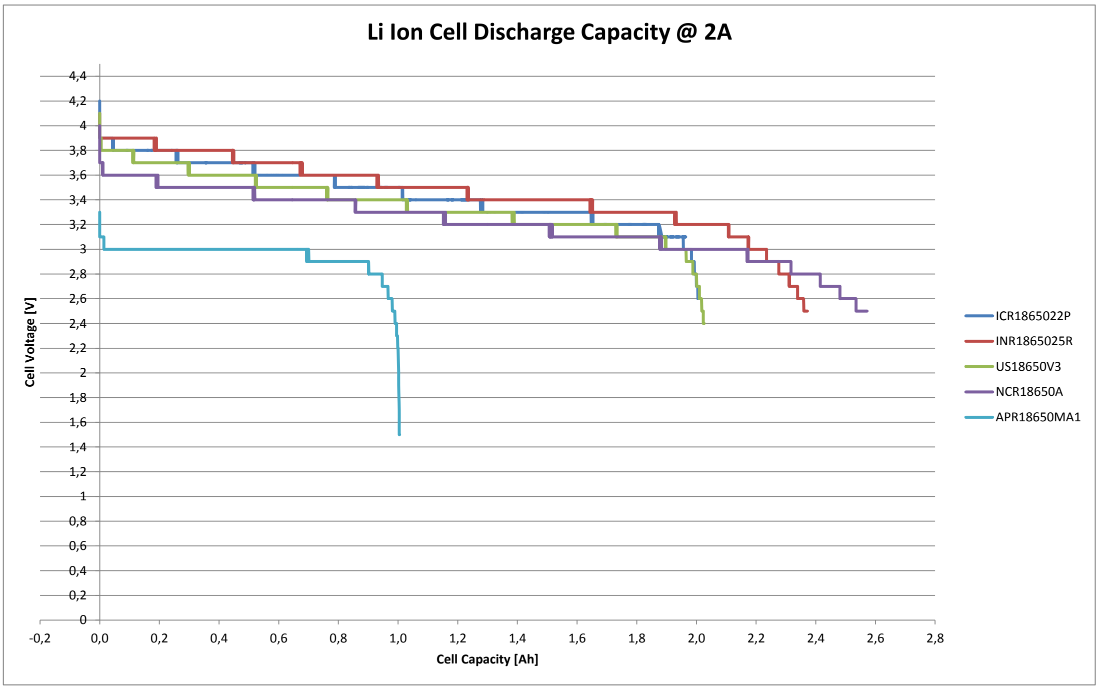


Figure 5.2.: Li-Ion Cells Specific Energy, Power and Density @ 2A Rate

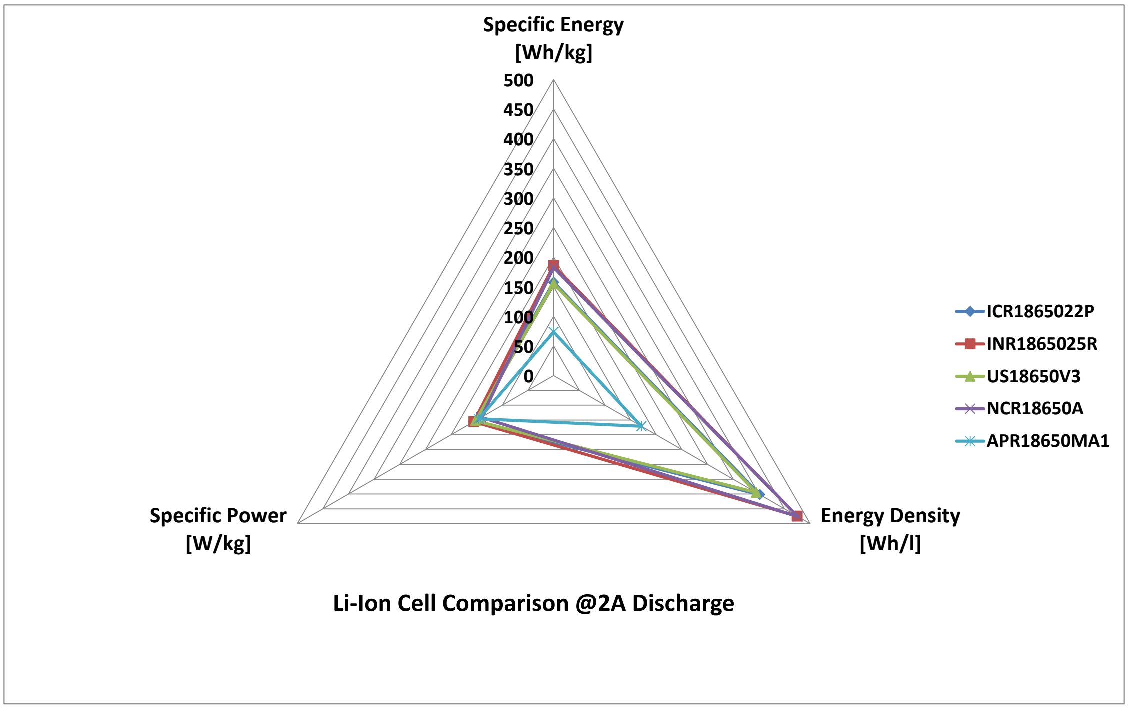


Figure 5.3.: Discharge Curves Comparison @ 3A Rate

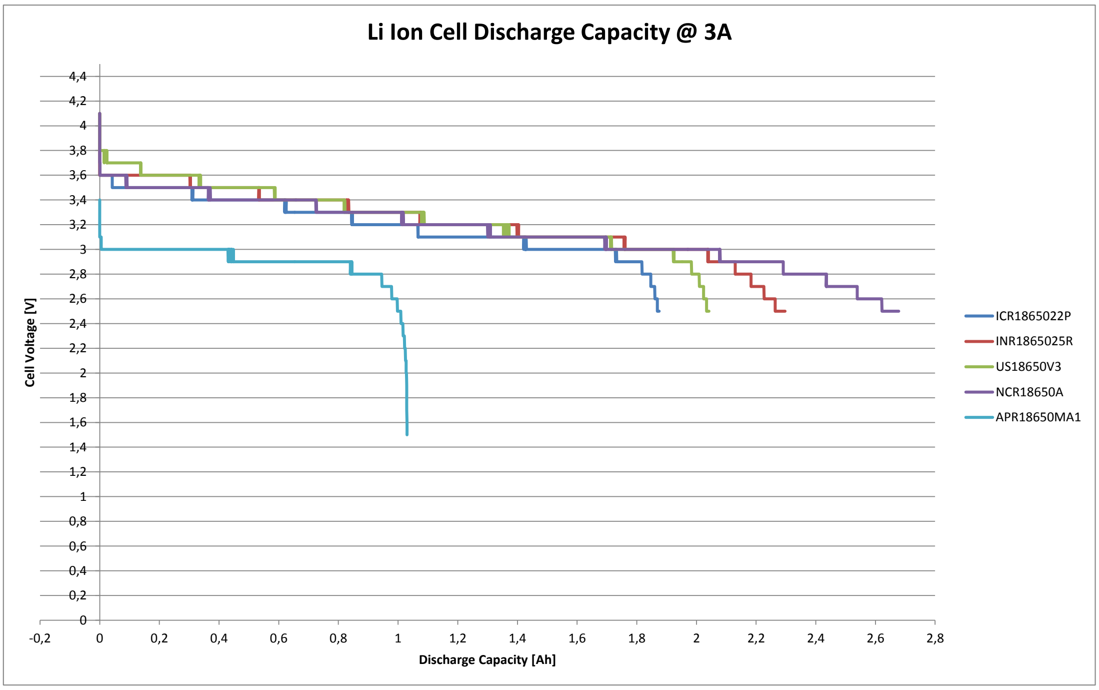


Figure 5.4.: Li-Ion Cells Specific Energy, Power and Density @ 3A Rate

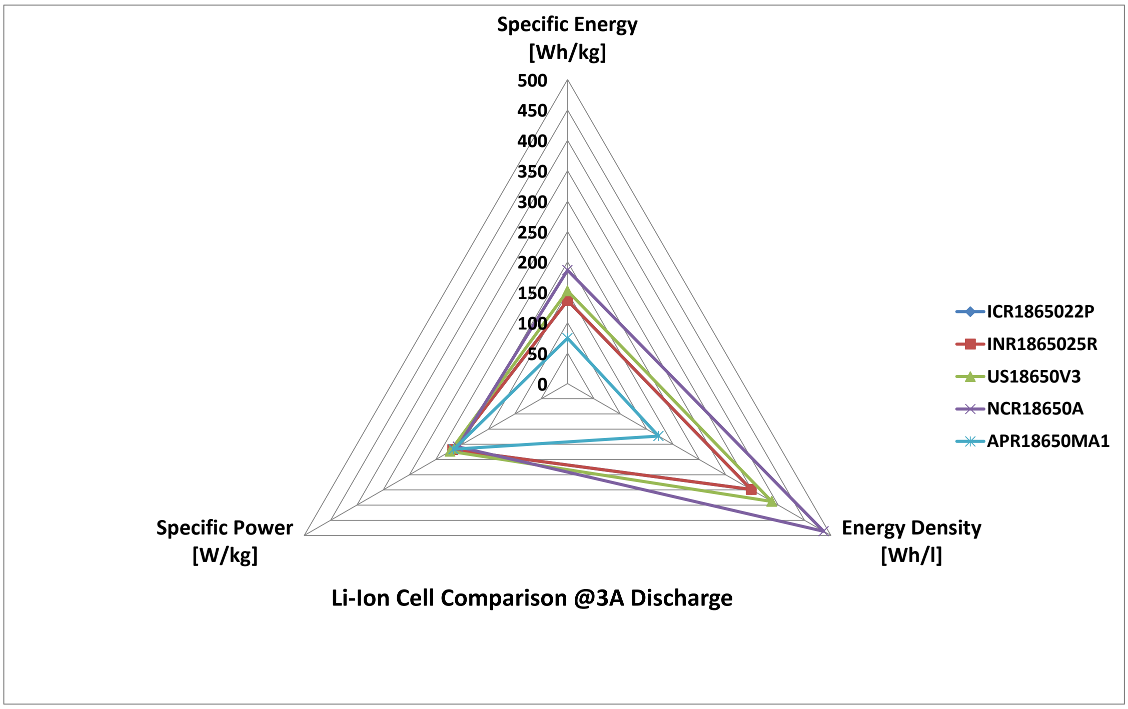


Figure 5.5.: Li-Ion Cells Discharge Curves Comparison @ 5A Rate

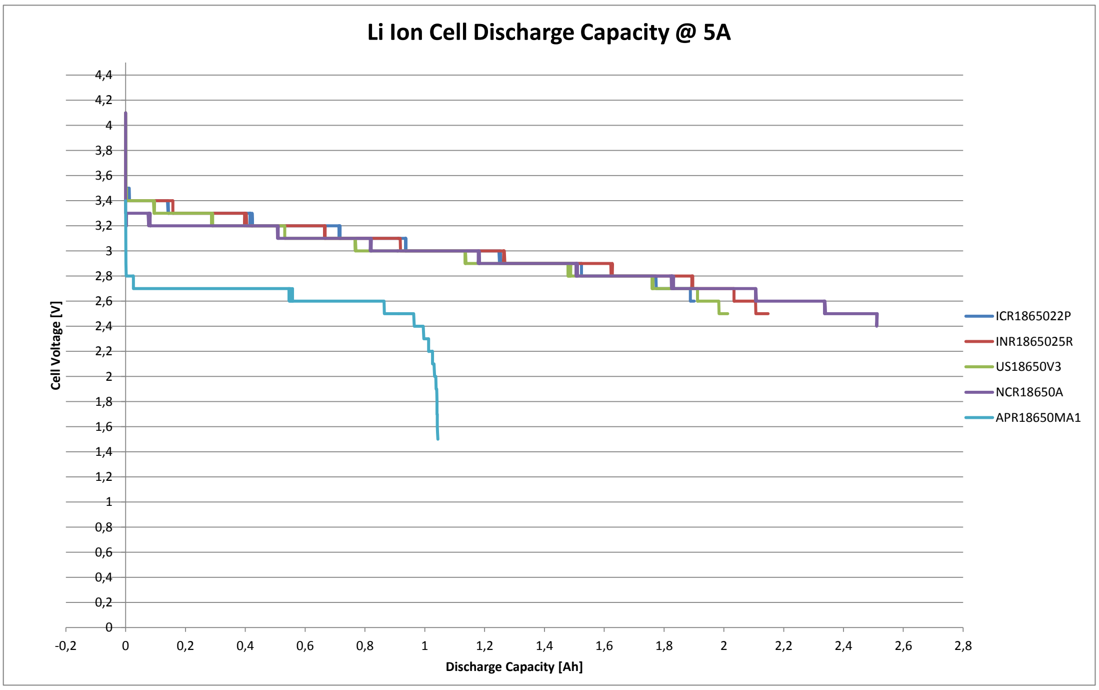
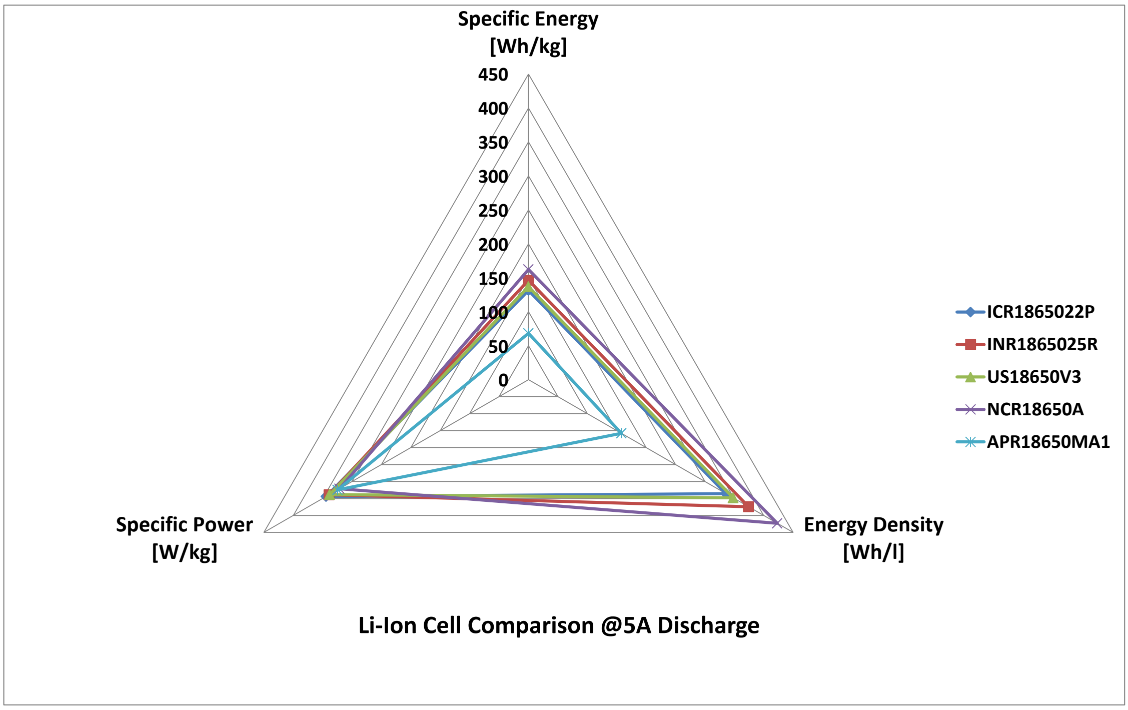


Figure 5.6.: Li-Ion Cells Specific Energy, Power and Density @ 5A Rate



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List of Abbreviations

AGM Absorbed Glass Mat

EV Electric Vehicles

HEV Hybrid Electric Vehicles

PHEV Plug-in Hybrid Electric Vehicles

BEV Battery Electric Vehicles

NiMH Nickel Metal Hydrid

Li-Ion Lithium Ion

Li-Po Lithium Polymer

UPS Uninterruptable Power Supply

SOC State of Charge

OCV Open Circuit Voltage

DOD Depth of Discharge

SOH State of Health

BMS Battery Management System

e-bike Electrical Bike

LEV Light Electric Vehicle

VRLA Valve Regulated Lead-Acid

AGM Absorbent Glass Mat

SLA Sealed Lead Acid

UPS Uninterrupted Power Supply

IR Internal Resistance

A Appendix

Spec. No.	ICR18650-22P	Version No.	1.0

SPECIFICATION OF PRODUCT

for Lithium-ion Rechargeable Cell

Model : ICR18650-22P

Mar, 2010

Samsung SDI Co., Ltd.

Battery Business Division

Spec. No.	ICR18650-22P	Version No.	1.0

Revision No.	Revision date	Page	Item	Description	Remark
01	15/ 03/ 2010			Formulated first edition	J.Y.Cho

Spec. No.	ICR18650-22P	Version No.	1.0

1. Scope

This product specification has been prepared to specify the rechargeable lithium-ion cell ('cell') to be supplied to the customer by Samsung SDI Co., Ltd.

2. Description and Model

2.1 Description Cell (lithium-ion rechargeable cell)

2.2 Model ICR18650-22P

3. Nominal Specifications

Item	Specification
3.1 Typical Capacity	2150mAh (0.2C, 2.75V discharge)
3.2 Minimum Capacity	2050mAh (0.2C, 2.75V discharge)
3.3 Charging Voltage	4.2V±0.05 V
3.4 Nominal Voltage	3.62V (1C discharge)
3.5 Charging Method	CC-CV (constant voltage with limited current)
3.6 Charging Current	Standard charge: 1075mA Rapid charge : 2150mA
3.7 Charging Time	Standard charge : 3hours Rapid charge : 2.5hours
3.8 Max. Charge Current	2150mA
3.9 Max. Discharge Current	10A (Continuous discharge)
3.10 Discharge Cut-off Voltage	2.75V
3.11 Cell Weight	44.5g max
3.12 Cell Dimension	Diameter(max.) : Φ 18.40 mm Height : 65mm max
3.13 Operating Temperature (Cell Surface temperature)	Charge : -10 to 50℃ Discharge: -20 to 70℃ * No Safety Issue but performance may be fade
3.14 Storage Temperature	1 year : -20~25℃(1*) 3 months : -20~45℃(1*) 1 month : -20~60℃(1*)

Note (1): If the cell is kept as ex-factory status(50% of charge), the capacity recovery rate is more than 80%.

4. Outline Dimensions

See the attachment(Fig. 1)

5. Appearance

There shall be no such defects as scratch, rust, discoloration, leakage which may adversely affect commercial value of the cell.

6. Standard Test Conditions

6.1 Environmental Conditions

Unless otherwise specified, all tests stated in this specification are conducted at temperature 25±5℃ and humidity 65±20%.

6.2 Measuring Equipment

(1) Ammeter and Voltmeter

The ammeter and voltmeter should have an accuracy of the grade 0.5 or higher.

(2) Slide caliper

The slide caliper should have 0.05 mm scale.

(3) Impedance meter

The impedance meter with AC 1kHz should be used.

7. Characteristics

7.1 Standard Charge

This "Standard Charge" means charging the cell with charge current 1075mA and constant voltage 4.2V at 25℃, 0.02C cutoff.

7.2 Standard Discharge Capacity

The standard discharge capacity is the initial discharge capacity of the cell, which is measured with discharge current of 430mA with 2.75V cut-off at 25℃ within 1 hour after the Standard charge.

Standard Discharge Capacity ≥ 2050mAh

7.3 Rated Discharge Capacity

The rated discharge capacity is the initial discharge capacity of the cell, which is measured with discharge current of 2150mA with 2.75V cut-off at 25℃ within 1 hour after the Standard charge.

Rated Discharge Capacity ≥ 2000mAh

7.4 Initial internal impedance

Initial internal impedance measured at AC 1kHz after Standard charge.

Initial internal impedance ≤ 35mΩ

7.5 Temperature Dependence of Discharge Capacity

Discharge capacity comparison at each temperature, measured with discharge constant current 2150mA and 2.75V cut-off with follow temperature after the standard charging at 25℃.

Charge Temperature	Discharge temperature			
25℃	-10℃	0℃	25℃	45℃
Relative Capacity	60%	80%	100%	100%

Note: If charge temperature and discharge temperature is not the same,
the interval for temperature change is 3 hours.
Percentage as an index of the Rated discharge capacity(=2000mAh) is 100%.

7.6 Temperature Dependence of Charge Capacity

Capacity comparison at each temperature, measured with discharge constant current 2150mA and 2.75V cut-off at 25℃ after the Standard charge is as follow temperature.

	Charge temperature			Discharge temperature
	0℃	25℃	45℃	25℃
Relative Capacity	80%	100%	100%	

Note: If charge temperature and discharge temperature is not the same,
the interval for temperature change is 3 hours.
Percentage as an index of of the Rated discharge capacity(=2000mAh) is 100%.

7.7 Charge Rate Capabilities

Discharge capacity is measured with constant current 2150mA and 2.75V cut-off after the cell is charged with 4.2V as follows.

	Charge Condition	
Current	0.5C (1075mA)	1.0C (2150mA)
Cut-off	3h or 0.02C	2.5h or 0.02C
Relative Capacity	100%	97%

Note: Percentage as an index of the Rated discharge capacity(=2000mAh) is 100%.

7.8 Discharge Rate Capabilities

Discharge capacity is measured with the various currents in under table and 2.75V cut-off after the standard charge.

	Discharge Condition			
Current	0.2C (430mA)	1C (2150mA)	3C (6450mA)	4.6C (10000mA)
Relative Capacity	100%	97%	95%	95%

Note: Percentage as an index of the capacity at 0.2C (=2050mAh) is 100%.

7.9 Cycle Life (1)

Each cycle is an interval between the charge (charge current 2150mA) with 0.05C cutoff and the discharge (discharge current 2150mA) with 2.75V cut-off.
Capacity after 500cycles.

Capacity ≥ 1400mAh (70% of Rated Capacity)

7.10 Cycle Life (2)

Each cycle is an interval between the charge (charge current 2150mA) with 0.05C cutoff and the discharge (discharge current 4300mA) with 2.75V cut-off.
Capacity after 300cycles

Capacity ≥ 1600mAh (80% of Rated Capacity)

7.11 Storage Characteristics

Capacity after storage for 30days at 60℃ after the Standard charged, measured with discharge current 2150mA with 2.75V cut-off at 25℃.

Capacity recovery(after the storage) ≥ 1800mAh (90% of Rated Capacity)

7.12 Status of the cell as of ex-factory

The cell should be shipped in 3.75V ~ 3.85V Charging voltage range.

8. Mechanical Characteristics

8.1 Drop Test

Test method: Cell(as of shipment or full charged) drop onto the oak-board (thickness: ≥30mm) from 1.5m height at a random direction 6 times.

Criteria: No leakage

8.2 Vibration Test

Sample condition: Fully charged state 5samples

Test Method: 20±5℃/ 1.6mm max. excursion / 1hertz/minute between 10hertz to 55hertz to 10Hertz / for mutually perpendicular directions

Criteria: No ventilation and leakage

(Test shall be performed with the following criteria IEC 62133, UL1642)

9. Safety

9.1 Overcharge Test

Test method: To charge the standard charged cell with 12V and 2150mA at 25℃ for 2.5 hours.

Criteria: No fire, and no explosion.

9.2 External Short-circuit Test

Test method: To short-circuit the standard charged cell by connecting positive and negative terminal by less than 100mΩ wire for 3 hours.

Criteria: No fire, and no explosion.

9.3 Reverse Charge Test

Test method: To charge reversely the standard charged cell with charge current 2150mA for 2.5 hours.

Criteria: No fire, and no explosion.

9.4 Heating Test

Test method: To heat the standard charged cell at heating rate of 5℃ per minute up to 130℃ and keep the cell in oven for 60 minutes.

Criteria: No fire, and no explosion.

9.5 Nail Penetrating Test

Test method: Cell shall be fully charged. Penetrate completely center of cell with 2.5mm diameter nail at the velocity of 150 mm/sec.

Criteria: No fire, and no explosion.

10. Warranty

Samsung SDI will be responsible for replacing the cell against defects or poor workmanship for 1year from the date of shipping. Any other problems caused by malfunction of the equipment or unsuitable use of the cell are not under this warranty.

The warranty set forth in proper use, handling conditions described above, and excludes in the case of a defect which is not related to manufacturing of the cell.

11. Others

11.1 Storage for a long time

If the cell is kept for a long time(3months or more), It is strongly recommended that the cell is preserved at dry and low-temperature.

11.2 Other

Any matters that specifications does not have, should be conferred with between the both parties.

12. Packaging

See Fig.2,
Package Drawing

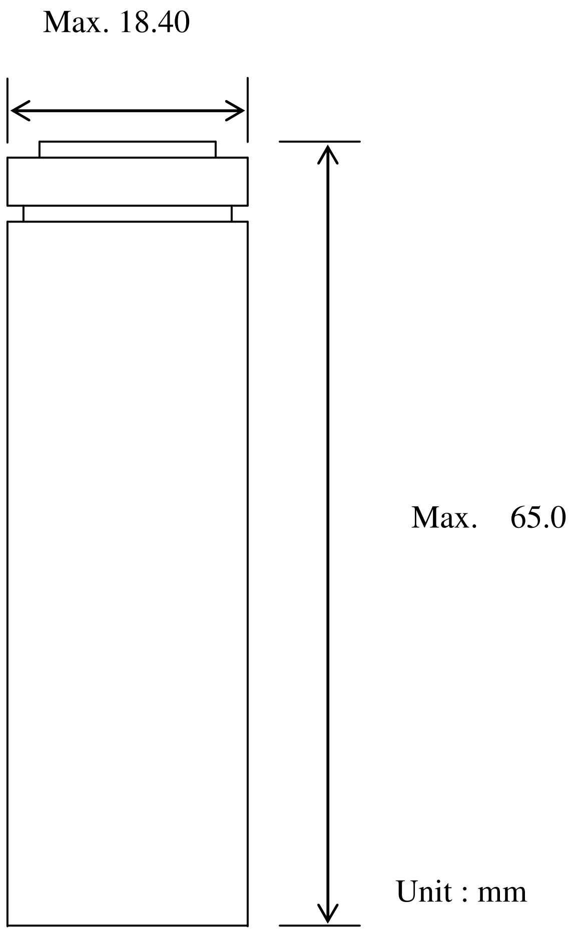


Fig. 1 Outline Dimensions of ICR18650-22P

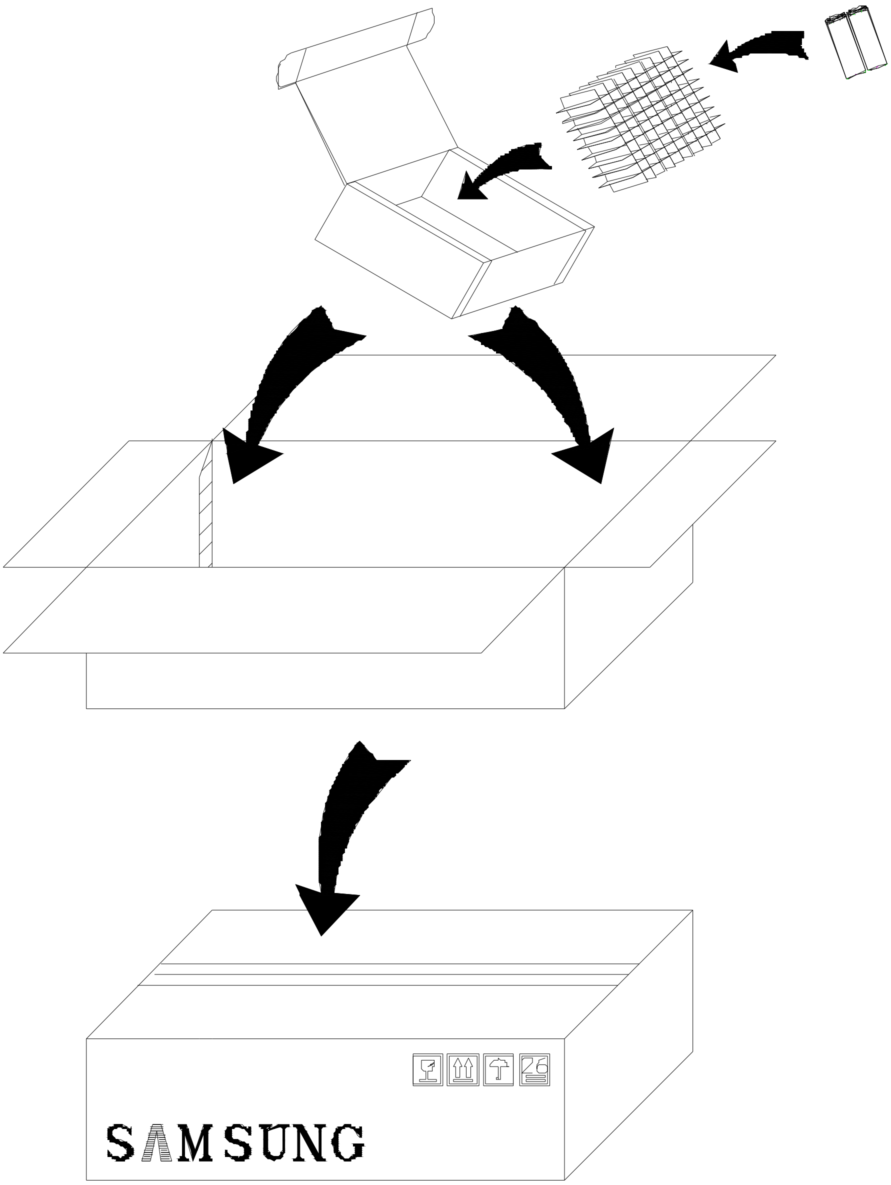


Fig 2. Package Drawing

Pack Quality Requirement for safety and quality epidemic issue.

1-1 The battery pack's consumption current.
- Sleep Mode : Under 250uA.
- Shut Down Mode : Under 10uA / Under 3.0V.
  Under 1uA / Under 2.5V.

1-2 SOC 0%
- Cell voltage in SOC 0% of Pack should be Min. 3.0V.
  (Discharging Cut-off Voltage)

1-3 Operating Charging Voltage of a cell.
- Normal operating voltage of a cell is 4.20V
- Max operating voltage of a cell is 4.25V.

1-4. No continuous charge
- Charge cut-off condition : Cut-off Current over than 1/20C(Charging method: CC-CV)
- Initial recharging condition : Remaining Capacity under than 90% or voltage under than 4.10V

1-5. Pre-charging function
- Pre-charge function should be implemented to prevent abnormal high rate charging after deep discharge.
- Pre-charging condition Operation : Under 3.0V
  Charging current : Under 150mA/Cell.(Continuous)
  Pre-charge stop (Normal Charge Start) : All cells reach 3.0V

1-6 Pre-charging function.
- Pre-charge function should be implemented to prevent abnormal high rate charging after deep discharge.
- Pre-charging condition
  : Operation : Under 3.0V
  Charging current : <150mAh/Cell.

1-7 Mechanical Guides.
- PCBA and Cell stack should have heat insulation material between them.(Such as plastic barrier which is giving air isolation or non-thermal conductive material.)
- B+ and B- wire connection should not be crossed each other. Do not make wire which had the voltage difference more than 4.0V get together.
- The material such as double sided tape and rubber which are used in battery pack should be verified for its flammability

If Pack cannot meet above requirement,
we cannot take responsibility for quality issue.

Proper Use and Handling of Lithium Ion Cells

See before using lithium-ion cell
Supplied by
Samsung SDI Co., Ltd.

1. General

This document has been prepared to describe the appropriate cautions and prohibitions, which the customer should take or employ when the customer uses and handles the lithium ion cell to be manufactured and supplied by Samsung SDI Co., Ltd., in order to obtain optimum performance and safety.

2. Charging

2.1 Charging current

Charging current should be less than maximum charge current specified in the product specification.

2.2 Charging voltage

Charging should be done by voltage less than that specified in the product specification.

2.3 Charging time

Continuous charging under appropriate voltage does not cause any loss of characteristics. However, the charge timer is recommended to be installed from a safety consideration, which shuts off further charging at time specified in the product specification.

2.4 Charging temperature

The cell should be charged within a range of specified temperatures in the product specification.

2.5 Reverse charging

The cell should be connected, confirming that its poles are correctly aligned. Inverse charging should be strictly prohibited. If the cell is connected improperly, it may be damaged.

3. Discharging

3.1 Discharging

3.1.1 The cell should be discharged at less than maximum discharge current specified in the product specification.

3.2 Discharging temperature

3.2.1 The cell should be discharged within a range of temperatures specified in the product specification.

3.2.2 Otherwise, it may cause loss of characteristics.

3.3 Over-discharging

3.3.1 The system should be equipped with a device to prevent further discharging exceeding discharging cut-off voltage specified in the product specification.(over-discharging)
3.3.2 Over-discharging may cause loss of performance, characteristics, of battery function.
3.3.3 Over-discharging may occur by self-discharge if the battery is left for a very long time without any use.
3.3.4 The charger should be equipped with a device to detect cell voltage and to determine recharging procedures.

4. Storage

4.1 Storage conditions
4.1.1 The cell should be stored within a range of temperatures specified in the product specification.
4.1.2 Otherwise, it may cause loss of characteristics, leakage and/or rust.

4.2 Long-term storage
4.2.1 The cell should be used within a short period after charging because long-term storage may cause loss of capacity by self-discharging.
4.2.2. If long-term storage is necessary, the cell should be stored at lower voltage within a range specified in the product specification, because storage at higher voltage may cause loss of characteristics.

5. Cycle life

5.1 Cycle life performance
5.1.1 The cell can be charged/discharged repeatedly up to times specified in the produce specification with a certain level of capacity also specified in the product specification.
5.1.2 Cycle life may be determined by conditions of charging, discharging, operating temperature and/or storage.

6. Design of System

6.1 Connection between the cell and the battery
6.1.1 The cell should not be soldered directly with leads. Namely, the cell should be welded with leads on its terminal and then be soldered with wire or leads to soldered lead.
6.1.2 Otherwise, it may cause damage of component, such as separator and insulator, by heat generation.

6.2 Positioning the battery in the System
6.2.1 The battery should be positioned as possible as far from heat sources and high temperature components.
6.2.2 Otherwise, it may cause loss of characteristics.

6.3 Mechanical shock protection of the battery

6.3.1 The battery should be equipped with appropriate shock absorbers in order to minimize shock.

6.3.2 Otherwise, it may cause shape distortion, leakage, heat generation and/or rupture.

6.4 Short-circuit protection of the cell

6.4.1 The cell is equipped with an insulating sleeve to protect short-circuit which may occur during transportation, battery assembly and /or system operation.

6.4.2 If the cell sleeve is damaged by some causes such as outside impact, it may cause short-circuit with some wiring inside the battery.

6.5 Connection between the battery and charger/system

6.5.1 The battery should be designed to be connected only to the specified charger and system.

6.5.2 A reverse connection of the battery, even in the specified system, should be avoided by employing special battery design such as a special terminals.

7. Battery Pack Assembly

7.1 Prohibition of usage of damaged cell

7.1.1 The cell should be inspected visually before battery assembly.

7.1.2 The cell should not be used if sleeve-damage, can-distortion and/or electrolyte-smell is detected.

7.2 Transportation

7.2.1 If the cell is necessary to transport to order place, such as the battery manufacturer, careful precautions should be taken to avoid damage of cell.

8. Others

8.1 Disassembly

8.1.1 The cell should not be dismantled from the battery pack.

8.1.2 Internal short-circuit caused by disassembly may lead to heat generation and/or venting.

8.1.3 When the electrolyte is coming in contact with the skin or eyes, wash immediately with fresh water and seek medical advice.

8.2 Short-circuiting

8.2.1 Short-circuit results in very high current which leads to heat generation.

8.2.2 An appropriate circuitry should be employed to protect accidental short-circuiting.

8.3 Incineration

8.3.1 Incinerating and disposing of the cell in fire are strictly prohibited, because it may cause rupture.

8.4 Immersion

8.4.1 Soaking the cell in water is strictly prohibited, because it may cause melt of components to damaged to functions.

8.5 Mixing use

8.5.1 Different types of cell, or same types but different manufacturer's cell may lead to cell rupture or damage to system due to the different characteristics of cell.

8.6 Battery disposal

8.6.1 Although the cell contains no environmentally hazardous component, such as lead or cadmium. the battery should be disposed according to the local regulations when it is disposed.

8.6.2 The cell should be disposed with a discharged state to avoid heat generation by an inadvertent short-circuit.

8.7 Caution - The Battery used in this device may present a risk of fire or chemical burn if mistreated. Do not disassemble, heat above 100℃ or incinerate. Replace battery with Samsung SDI battery only. Use of another battery may present a risk of fire or explosion. Dispose of used battery promptly. Keep away from children. Do not disassemble and do not dispose of in fire.

8.8 Warning – Attached

Handling Precaution and Prohibitions of Lithium Ion & Lithium Ion Polymer Rechargeable Cells and Batteries

Inaccurate handling of lithium ion and lithium ion polymer rechargeable battery may cause leakage, heat, smoke, an explosion, or fire.

This could cause deterioration of performance or failure. Please be sure to follow instructions carefully.

1.1 Storage

Store the battery at low temperature (below 20℃ is recommended), low humidity, no dust and no corrosive gas atmosphere.

1.2 Safety precaution and prohibitions

To assure product safety, describe the following precautions in the instruction manual of the application.

[Danger!]

■ Electrical misusage

Use dedicated charger.

Use or charge the battery only in the dedicated application.

Don't charge the battery by an electric outlet directly or a cigarette lighter charger.

Don't charge the battery reversely.

■ Environmental misusage

Don't leave the battery near the fire or a heated source.

Don't throw the battery into the fire.

Don't leave, charge or use the battery in a car or similar place where inside of temperature may be over 60℃.

Don't immerse, throw, wet the battery in water / seawater.

■ others

Don't fold the battery cased with laminated film such as pouch and Polymer.

Don't store the battery in a pocket or a bag together with metallic objects such as keys, necklaces, hairpins, coins, or screws.

Don't short circuit (+) and (-) terminals with metallic object intentionally.

Don't pierce the battery with a sharp object such as a needle, screw drivers.

Don't heat partial area of the battery with heated objects such as soldering iron.

Don't hit with heavy objects such as a hammer, weight.

Don't step on the battery and throw or drop the battery on the hard floor to avoid mechanical shock.

Don't disassemble the battery or modify the battery design including electric circuit.

Don't solder on the battery directly.

Don't use seriously scared or deformed battery.

Don't put the battery into a microwave oven, dryer ,or high-pressure container.

Don't use or assemble the battery with other makers' batteries, different types and/or models of batteries such as dry batteries, nickel-metal hydride batteries, or nickel-cadmium batteries.

Don't use or assemble old and new batteries together.

[Warning!]

Stop charging the battery if charging isn't completed within the specified time.

Stop using the battery if the battery becomes abnormally hot, order, discoloration, deformation, or abnormal conditions is detected during use, charge, or storage.

Keep away from fire immediately when leakage or foul odors are detected. If liquid leaks onto your skin or cloths, wash well with fresh water immediately.

If liquid leaking from the battery gets into your eyes, don't rub your eyes and wash them with clean water and go to see a doctor immediately.

If the terminals of the battery become dirty, wipe with a dry cloth before using the battery.

The battery can be used within the following temperature ranges. Don't exceed these ranges.

Charge temperature ranges : 0℃ ~ 45℃

Discharge Temperature ranges : -20℃ ~ 60℃

Store the battery at temperature below 60℃

Cover terminals with proper insulating tape before disposal.

[Caution!]

■ Electrical misusage

Battery must be charge with constant current-constant voltage (CC/CV).

Charge current must be controlled by specified value in Cell specification.

Cut-off Voltage of charging must be 4.2V.

Charger must stop charging battery by detecting either charging time or current specified in Cell's specification.

Discharge current must be controlled by specified value in Cell's specification.

Cut-off Voltage of discharging must be over 2.5V.

■ others

Keep the battery away from babies and children to avoid any accidents such as swallow.

If younger children use the battery, their guardians should explain the proper handling method and precaution before using.

Before using the battery, be sure to read the user's manual and precaution of it's handling.

Before using charger, be sure to read the user's manual of the charger.

Before installing and removing the battery from application, be sure to read user's manual of the application.

Replace the battery when using time of battery becomes much shorter than usual.

Cover terminals with insulating tape before proper disposal.

If the battery is needed to be stored for an long period, battery should be removed from the application and stored in a place where humidity and temperature are low.

While the battery is charged, used and stored, keep it away from object materials with static electric chargers.

Safety Handling Procedure for the Transporter

- Quarantine : Packages that are crushed, punctured or torn open to reveal contents should not be transported. Such packages should be isolated until the shipper has been consulted, provided instructions and, if appropriate, arranged to have the product inspected and repacked.
- Spilled Product : In the event that damage to packaging results in the release of cells or batteries, the spilled products should be promptly collected and segregated and the shipper should be contacted for instructions.

Design of positioning the battery pack in application and charger

To prevent the deterioration of the battery performance caused by heat, battery shall be positioned away from the area where heat is generated in the application and the charger.

Design of the Battery Pack

Be sure adopting proper safe device such as PTC specified type or model in Cell Specification. If you intend to adopt different safety device which is not specified in Cell Specification, please contact Samsung SDI to investigate any potential safety problem.

Be sure designing 2nd protective devices such as PTC & PCM at the same time to protect Cell just in case one protective device is fault.

Please contact following offices when you need any help including safety concerns.

Samsung SDI Emergency Contact Information

■ **Samsung SDI Headquarter.**

Samsung Life Insurance Bldg. 150 Taepyungro 2-ga, Jung-gu, Seoul, Korea
Tel:(+82)2-727-3686 Fax:(+82)2-727-3689

■ **Samsung SDI Chonan factory.**

508, Sungsung-Dong, Chonan City, Chungchongnam-Do, Korea
Tel:(+82)41-560-3669 Fax:(+82)41-560-3697

■ **Samsung SDI America office.**

18600 Broadwick Street Rancho Dominguez CA 90220
Tel:(+1)310-900-5205 Fax:(+1)310-537-1033

■ **Samsung SDI Taiwan office.**

Rm. 3010, 30F., 333, Keelung Rd. Sec. 1, Taipei, Taiwan
Tel:(+886)2-2728-8469 Fax:(+886)2-2728-8480

Spec. No.	INR18650-25R	Version No.	1.0	In-Young Jang

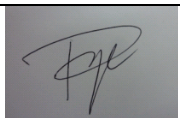
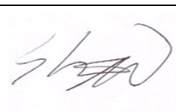
Specification

1.Customer : Hilti

2.Product : Lithium-ion Battery

3.SDI Model : INR18650-25R

4. Approved by

Division	Cylindrical Cell Product	Quality	Hilti
Signature			
Date	13/Feb /2014	13/Feb /2014	/ /

5.Date of Application (YY/MM/DD)

6.Supplier : **SAMSUNG SDI Co., Ltd.**
Energy Business Division

Feb , 2014

Samsung SDI Co.,Ltd.

Energy Business Division

Spec. No.	INR18650-25R	Version No.	1.0	In-Young Jang

Contents

Spec. No.	INR18650-25R	Version No.	1.0	In-Young Jang

1.0. Scope

This product specification has been prepared to specify the rechargeable lithium-ion cell ('cell') to be supplied to the customer by Samsung SDI Co., Ltd.

2.0. Description and model name

2.1 Description lithium-ion rechargeable cell

2.2 Model name INR18650-25R

3.0. Nominal specifications

Item	Specification
3.1 Nominal discharge capacity	2,500mAh Charge: 1.25A, 4.20V,CCCV 125mA cut-off, Discharge: 0.2C, 2.5V discharge cut-off
3.2 Nominal voltage	3.6V
3.3 Standard charge	CCCV, 1.25A, 4.20 ± 0.05 V, 125mA cut-off
3.4 Rapid charge	CCCV, 4A, 4.20 ± 0.05 V, 100mA cut-off
3.6 Charging time	Standard charge : 180min / 125mA cut-off Rapid charge: 60min (at 25℃) / 100mA cut-off
3.7 Max. continuous discharge (Continuous)	20A(at 25℃), 60% at 250 cycle
3.8 Discharge cut-off voltage End of discharge	2.5V
3.9 Cell weight	45.0g max
3.10 Cell dimension	Height : 64.85 ± 0.15mm Diameter : 18.33 ± 0.07mm
3.11 Operating temperature (surface temperature)	Charge : 0 to 60℃ (recommended recharge release < 45℃) Discharge: -20 to 75℃ (recommended re-discharge release < 60℃)
3.12 Storage temperature (Recovery 90% after storage)	1.5 year -30~25℃(1*) 3 months -30~45℃(1*) 1 month -30~60℃(1*)

Note (1): If the cell is kept as ex-factory status (50±5% SOC, 25℃),
the capacity recovery rate is more than 90% of 10A discharge capacity
100% is 2,450mAh at 25℃ with SOC 100% after formation.

4.0 Outline dimensions

See the attachment (Fig. 1)

5.0. Appearance

There shall be no such defects as scratch, rust, discoloration, leakage which may adversely affect commercial value of the cell.

6.0. Standard test conditions

6.1 Environmental conditions

Unless otherwise specified, all tests stated in this specification are conducted at temperature 25±5℃ and humidity 65±20%.

6.2 Measuring equipments

(1) Amp-meter and volt-meter

The amp-meter and volt-meter should have an accuracy of the grade 0.5mA and mV or higher.

(2) Slide caliper

The slide caliper should have 0.01 mm scale.

(3) Impedance meter

The impedance meter with AC 1kHz should be used.

7.0. Characteristics

7.1 Standard charge

This "Standard charge" means charging the cell CCCV with charge current 0.5CmA (1,250mA), constant voltage 4.2V and 125mA cut-off in CV mode at 25℃ for capacity. .

7.2 Rapid charge

Rapid charge means charging the cell CCCV with charge current 4A and 100mA cut-off at 25℃

7.3 Nominal discharge capacity

The standard discharge capacity is the initial discharge capacity of the cell, which is measured with discharge current of 500mA(0.2C) with 2.5V cut-off at 25℃ within 1hour after the standard charge.

Nominal discharge capacity ≥ 2,500mAh

Which complying to the minimum capacity of IEC61960 standard.

7.4 Standard rated discharge capacity

The standard rated discharge is the discharge capacity of the cell, which is measured with discharge current of 10A with 2.5V cut-off at 25℃ within 1hour after the standard charge.

Standard rated discharge capacity ≥ 2,450mAh

7.5 Initial internal impedance

Initial internal impedance measured at AC 1kHz after standard charge

Initial internal impedance ≤ 18mΩ

7.6 Temperature dependence of discharge capacity

Capacity comparison at each temperature, measured with discharge constant current 10A and 2.5V cut-off after the standard charge is as follows.

Discharge temperature				
-20℃	-10℃	0℃	25℃	60℃

60%	75%	80%	100%	100%

Note: If charge temperature and discharge temperature is not the same,
the interval for temperature change is 3 hours.
Percentage index of the discharge at 25℃ at 10A (=2,450mAh) is 100%.

7.7 Temperature dependence of charge capacity

Capacity comparison at each temperature, measured with discharge constant current 10A and 2.5V cut-off after the standard charge is as follows.

	Charge temperature					Discharge temperature
	0℃	5℃	25℃	45℃	60℃	25℃
Relative capacity	80%	90%	100%	95%	95%	

Note: If charge temperature and discharge temperature is not the same,
the interval for temperature change is 3 hours.
Percentage index of the discharge at 25℃ at 10A (=2,450mAh) is 100%.

7.8 Charge rate capabilities

Discharge capacity is measured with constant current 10A and 2.5V cut-off after the cell is charged with 4.2V as follows.

	Charge condition	
Current	Standard 1.25A	Maximum rapid charge 4A
Cut-off	125mA	100mA
Relative Capacity	100%	98%

Note: Percentage index of the discharge at 25℃ at 10A (=2,450mAh) is 100%.

7.9 Discharge rate capabilities

Discharge capacity is measured with the various currents in under table and 2.5V cut-off after the standard charge.

	Discharge condition				
Current	0.50A	5A	10A	15A	20A
Relative Capacity	100%	97%	100%	97%	95%

Percentage index of the discharge at 25℃ at 10A (=2,450mAh) is 100%.

7.10 Cycle life

With standard charge and maximum continuous discharge.
Capacity after 250cycles,

Capacity ≥ 1,500mAh (60% of the nominal capacity at 25℃)

7.11 Storage characteristics

Standard rated discharge capacity after storage for 1 month at 60℃ from the standard charged state is ≥ 90% of the initial 10A discharge capacity at 25℃

7.12 Status of the cell as of ex-factory

The cell should be shipped in 50 ± 5% charged state. In this case, OCV is from 3.600V to 3.690V.

8.0. Mechanical Characteristics

8.1 Drop test

Test method: Cell(as of shipment or full charged) drop onto a concrete from 1.0m height at 3 sides.

Criteria: No leakage, Voltage decrease≦0.025V, AC iR increase ≦1.0mΩ

8.2 Vibration test

Test method: As to the UN transportation regulation(UN38.3), for each axis (X and Y axis with cylindrical cells) 7Hz→200Hz→7Hz for 15min, repetition 12 times totally 3hours, the acceleration 1g during 7 to 18Hz and 8g (amplitude 1.6mm) up to 200Hz.

Criteria: No leakage, with less than 10mV of OCV drop

9.0. Safety

9.1 Overcharge test

Test method: To charge with 20A-20V at 25℃ for 3hr.

Criteria: No fire, and no explosion.

9.2 External short-circuit test

Test method: To short-circuit the standard charged cell (or 50% discharged cell) by connecting positive and negative terminal by 50mΩ wire for 10min.

Criteria: No fire, and no explosion.

9.3 Reverse charge test

Test method: To charge the standard charged cell with charge current 10A By 0V for 2.5 hours.

Criteria: No fire, and no explosion.

9.4 Heating test

Test method: To heat up the standard charged cell at heating rate 5℃ per minute up to 130℃ and keep the cell in oven for 10 minutes.

Criteria: No fire, and no explosion.

10.0. Warranty

Samsung SDI will be responsible for replacing the cell against defects or poor workmanship for 18months from the date of shipping. Any other problem caused by malfunction of the equipment or mix-use of the cell is not under this warranty.

The warranty set forth in proper using and handling conditions described above and excludes in the case of a defect which is not related to manufacturing of the cell.

11.0. Others

11.1 Storage for a long time

If the cell is kept for a long time (3 months or more), It is strongly recommended that the cell is preserved at dry and low-temperature.

11.2 Others

Any matters that specifications do not have, should be conferred with between the both parties.

12.0. Packing

See Fig.2,

Package Drawing

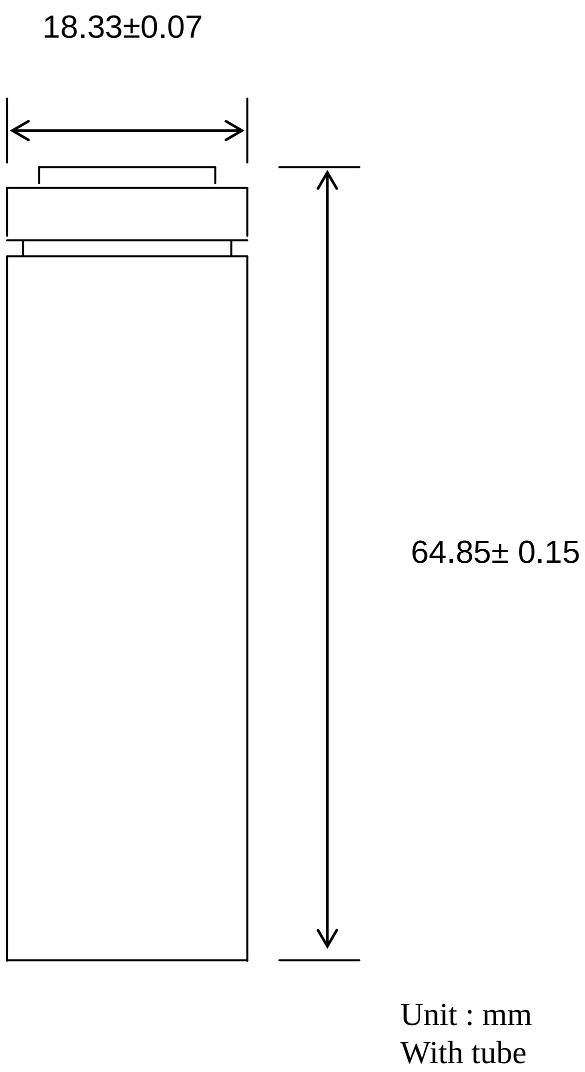


Fig.1. Outline dimensions of INR110500-25R

NO	PART NAME	MATERIAL	MATERIAL DIM	Q'TY
01	INR18650(Ref. Model List)	BARE CELL	ø18, H65	200
02	PACKING GUIDE	MANILA	L192×W191×H67	200
03	PACKING CASE IN	SW-1(B FLUTE)	L192×W192×H68	2
04	SILICAGEL	SI	L50×W50,3G	2
05	PE BAG(LARGE)	PE	L500×W450×T0.028	1
06	TAPE	PE(OPP)	W50×T0.05	1
07	PACKING CASE OUT	DW-1(BA FLUTE)	L225×W214×H164	1
08	LABEL	ART PAPER	L52×W100	1

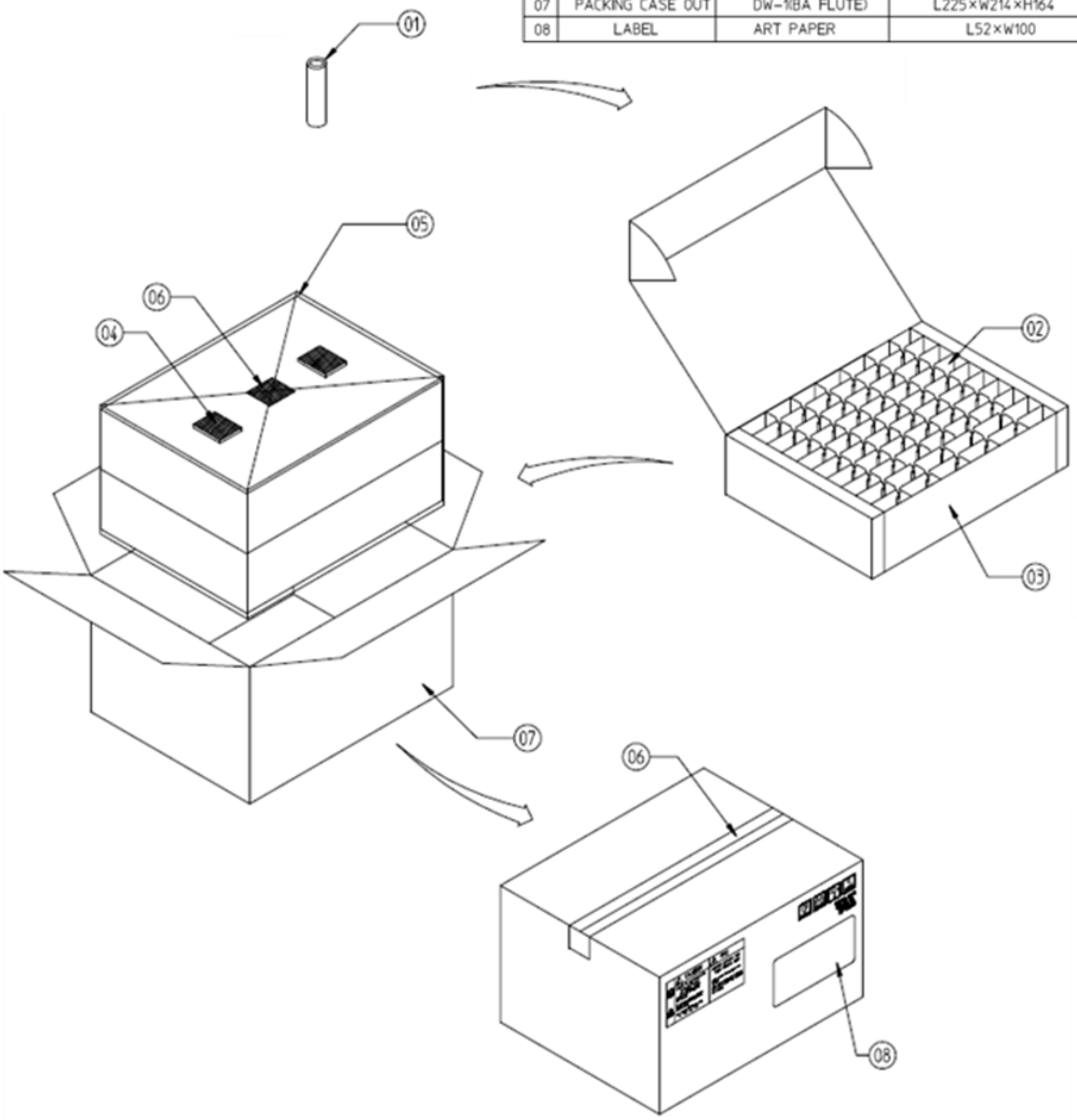


Fig.2. Package drawing

Spec. No.	INR18650-25R	Version No.	1.0	In-Young Jang

Proper use and handling of lithium ion cells

See before using lithium-ion cell
Supplied by
Samsung SDI Co., Ltd.

1.0. General

This document has been prepared to describe the appropriate cautions and prohibitions, which the customer should take or employ when the customer uses and handles the lithium ion cell to be manufactured and supplied by Samsung SDI Co., Ltd., in order to obtain optimal performance and safety.

2.0. Charging

2.1 Charging current

Charging current shall be less than maximum charge current specified in the product specification.

2.2 Charging voltage

Charging shall be done by voltage less than that specified in the product specification.

2.3 Charging time

Continuous charging under specified voltage does not cause any loss of performance characteristics. However, the charge timer is recommended to be installed from a safety consideration, which shuts off further charging at time specified in the product specification.

2.4 Charging temperature

The cell shall be charged within a range of specified temperatures in the specification.

2.5 Reverse charging

The cell shall be connected, confirming that its poles are correctly aligned.
Inverse charging shall be strictly prohibited. If the cell is connected improperly, it may be damaged.

3.0. Discharging

3.1 Discharging

3.1.1 The cell shall be discharged continuously at less than maximum discharge current specified in the product specification. In case of the higher discharge current should be set, it shall be discussed together with SDI.

3.2 Discharging temperature

3.2.1 The cell shall be discharged within a range of temperatures specified in the product specification.

3.2.2 Otherwise, it may cause loss of performance characteristics.

3.3 Over-discharging

3.3.1 The system should equip with a device to prevent further discharging exceeding discharging cut-off voltage specified in the product specification.

3.3.2 Over-discharging may cause loss of performance characteristics of battery.

3.3.3 Over-discharging may occur by self-discharge if the battery is left for a very long time without any use.

3.3.4 The charger should equip with a device to detect voltage of cell block and to determine recharging procedures.

4.0. Storage

4.1 Storage conditions

4.1.1 The cell should be stored within a range of temperatures specified in the product specification.

4.1.2 Otherwise, it may cause loss of performance characteristics, leakage and/or rust.

4.2 Long-term storage

4.2.1 The cell should be used within a short period after charging because long-term storage may cause loss of capacity by self-discharging.

4.2.2. If long-term storage is necessary, the cell should be stored at lower voltage within a range specified in the product specification, because storage with higher voltage may cause more loss of performance characteristics.

5.0. Cycle life

5.1 Cycle life performance

5.1.1 The cell can be charged/discharged repeatedly up to times specified in the product specification with a certain level of capacity specified in the product specification.

5.1.2 Cycle life may be determined by conditions of charging, discharging, operating temperature and/or storage.

6.0. Design of system

6.1 Connection between the cell and the battery

6.1.1 The cell should not be soldered directly with other cells. Namely, the cell should be welded with leads on its terminal and then be soldered with wire or leads to solder.

6.1.2 Otherwise, it may cause damage of component, such as separator and insulator, by heat generation.

6.2 Positioning the battery in the system

6.2.1 The battery should be positioned as possible as far from heat sources and high temperature components.

6.2.2 Otherwise, it may cause loss of characteristics.

6.2.3 The recommended spacing between the cells is more than 1mm.

6.3 Mechanical shock protection of the battery

6.3.1 The battery should be equipped with appropriate shock absorbers in the pack in order to minimize shock, which can damage the cells.

6.3.2 Otherwise, it may cause shape distortion, leakage, heat generation and/or rupture and/or open circuit.

6.4 Short-circuit protection of the cell

6.4.1 The cell equips with an insulating sleeve to protect short-circuit which may occur during transportation, battery assembly and /or system operation.

6.4.2 If the cell sleeve is damaged by some cause such as outside impact, it may cause short-circuit with some wiring inside the battery.

6.5 Connection between the battery and charger/system

6.5.1 The battery should be designed to be connected only to the specified charger and system.

6.5.2 A reverse connection of the battery, even in the specified system, should be avoided by employing special battery design such as a special terminals.

6.6 Pack design

6.6.1 The current consumption of the battery pack should be under 10uA at sleep mode.

6.6.2 Cell voltage monitoring system.

The system (charger or pack) should be equipped with a device to monitor each voltage of cell block to avoid cell imbalance which can cause damage to the cells.

6.6.4 The battery pack or system should have warning system such as over temperature, over voltage, over current, and so on.

7.0. Battery pack assembly

7.1 Prohibition of usage of damaged cell

7.1.1 The cell should be inspected visually before battery assembly.

7.1.2 The cell should not be used if sleeve-damage, can-distorsion and/or electrolyte-smell is detected.

7.2 Terminals handling

7.2.1 Excessive force on the negative terminal should be avoided when external strip terminal is welled.

7.3 Transportation

7.3.1 If the cell is necessary to be transported to such as the battery manufacturer, careful precautions should be taken to avoid damage of cell.

8.0. Others

8.1 Disassembly

8.1.1 The cell should not be dismantled from the battery pack.

8.1.2 Internal short-circuit caused by disassembly may lead to heat generation and/or venting.

8.1.3 When the electrolyte is coming in contact with the skin or eyes, flush immediately with fresh water and seek medical advice.

8.2 Short-circuiting

8.2.1 Short-circuit results in very high current which leads to heat generation.

8.2.3 An appropriate circuitry should be employed to protect accidental short-circuiting.

8.3 Incineration

8.3.1 Incinerating and disposing of the cell in fire are strictly prohibited, because it may cause rupture and explosion.

8.4 Immersion

8.4.1 Soaking the cell in water is strictly prohibited, because it may cause corrosion and leakage of components to be damaged to functions

8.5 Mixing use

8.5.1 Different types of cell, or same types but different cell manufacturer's shall not be used, which may lead to cell imbalance, cell rupture or damage to system due to the different characteristics of cell.

8.6 Battery exchange

8.6.1 Although the cell contains no environmentally hazardous component, such as lead or cadmium, the battery shall be disposed according to the local regulations when it is disposed.

8.6.2 The cell should be disposed with a discharged state to avoid heat generation by an inadvertent short-circuit.

8.7 Caution

The Battery used in this device may present a risk of fire or chemical burn if mistreated.

Do not disassemble, expose to heat above 100℃ or incinerate it.

Replace battery with those of Samsung SDI only.

Use of another battery may cause a risk of fire or explosion.

Dispose of used battery promptly.

Keep battery away from children.
Do not disassemble and do not dispose of battery in fire.

8.8 Warning – Attached

Handling precaution and prohibitions of lithium Ion rechargeable cells and batteries

Inaccurate handling of lithium ion and lithium ion polymer rechargeable battery may cause leakage, heat, smoke, an explosion, or fire.

This could cause deterioration of performance or failure. Please be sure to follow instructions carefully.

1.1 Storage

Store the battery at low temperature (below 25℃ is recommended), low humidity, no dust and no corrosive gas atmosphere.

1.2 Safety precaution and prohibitions

To assure product safety, describe the following precautions in the instruction manual of the application.

[Danger!]

■ Electrical misusage

Use stipulated charger.

Use or charge the battery only in the stipulated application.

Don't charge the battery by an electric outlet directly or a cigarette lighter charger.

Don't charge the battery reversely.

■ Environmental misusage

Don't leave the battery near the fire or a heated source.

Don't throw the battery into the fire.

Don't leave, charge or use the battery in a car or similar place where inside of temperature may be over 60℃.

Don't immerse, throw, wet the battery in water / sea water.

■ others

Don't fold the battery cased with laminated film such as pouch and polymer.

Don't store the battery in a pocket or a bag together with metallic objects such as keys, necklaces, hairpins, coins, or screws.

Don't short circuit (+) and (-) terminals with metallic object intentionally.

Don't pierce the battery with a sharp object such as a needle, screw drivers.

Don't heat partial area of the battery with heated objects such as soldering iron.

Don't hit with heavy objects such as a hammer, weight.

Don't step on the battery and throw or drop the battery on the hard floor to avoid mechanical shock.

Don't disassemble the battery or modify the battery design including electric circuit.

Don't solder on the battery directly.

Don't use seriously scared or deformed battery.

Don't put the battery into a microwave oven, dryer or high-pressure container.

Don't use or assemble the battery with other makers' batteries, different types and/or models of batteries such as dry batteries, nickel-metal hydride batteries, or nickel-cadmium batteries.

Don't use or assemble old and new batteries together.

[Warning!]

Stop charging the battery if charging isn't completed within the specified time.

Stop using the battery if the battery becomes abnormally hot, order, discoloration, deformation, or abnormal conditions is detected during use, charge, or storage.

Keep away from fire immediately when leakage or foul odors are detected. If liquid leaks onto your skin or cloths, wash well with fresh water immediately.

If liquid leaking from the battery gets into your eyes, don't rub your eyes and wash them with clean water and go to see a doctor immediately.

If the terminals of the battery become dirty, wipe with a dry cloth before using the battery.

The battery can be used within the following temperature ranges. Don't exceed these ranges.

The operating temperature is based on the cell surface temperature in hottest position in pack.

Charge temperature ranges : 0℃ ~ 60℃

Discharge Temperature ranges : -20℃ ~ 75℃

Store the battery at temperature below 60℃

Cover terminals with proper insulating tape before disposal.

[Caution!]

■ Electrical misusage

Battery must be charged with constant current-constant voltage (CC/CV).

Charge current must be controlled by specified value in cell specification.

Cut-off voltage of charging must be less than 4.2 + 0.05V

Charger must stop charging battery by detecting either charging time or current specified in cell’s specification.

Discharge current must be controlled by specified value in cell’s specification.

Cut-off voltage of full discharging and recharging must be over 2.5V.

■ others

Keep the battery away from babies and children to avoid any accidents such as swallow.

If younger children use the battery, their guardians should explain the proper handling method and precaution before using.

Before using the battery, be sure to read the user's manual and precaution of it's handling.

Before using charger, be sure to read the user's manual of the charger.

Before installing and removing the battery from application, be sure to read user's manual of the application.

Replace the battery when using time of battery becomes much shorter than usual.

Cover terminals with insulating tape before proper disposal.

If the battery is needed to be stored for an long period, battery should be removed from the application and stored in a place where humidity and temperature are low.

While the battery is charged, used and stored, keep it away from object materials with static electric chargers.

Safety handling procedure for the transporter

■ Quarantine

Packages that are crushed, punctured or torn open to reveal contents should not be transported. Such packages should be isolated until the shipper has been consulted, provided instructions and, if appropriate, arranged to have the product inspected and repacked.

■ Spilled product

In the event that damage to packaging results in the release of cells or batteries, the spilled products should be promptly collected and segregated and the shipper should contact for instructions.

Design of positioning the battery pack in application and charger

To prevent the deterioration of the battery performance caused by heat, battery shall be positioned away from the area where heat is generated in the application and the charger.

Design of the battery pack

Be sure adopting proper safe device such as PTC specified type or model in Cell Specification. If you intend to adopt different safety device which is not specified in Cell Specification, please contact Samsung SDI to investigate any potential safety problem.

Be sure designing 2nd protective devices such as PCM at the same time to protect cell just in case one protective device is fault.

Please contact following offices when you need any help including safety concerns.

Spec. No.	INR18650-25R	Version No.	1.0	In-Young Jang

Samsung SDI emergency contact information

■ **Samsung SDI Cheonan factory CS group**

508, Sungsung-dong, Cheonan-si, Chungnam, Korea

Tel:(+82)70-7125-1806 Fax:(+82)41-560-3697

■ **Samsung SDI America office.**

18600 Broadwick Street Rancho Dominguez CA 90220

Tel:(+1)310-900-5205 Fax:(+1)310-537-1033

■ **Samsung SDI Taiwan office.**

Rm. 3010, 30F., 333, Keelung Rd. Sec. 1, Taipei, Taiwan

Tel:(+886)2-2728-8469 Fax:(+886)2-2728-8480

Additional remarks

■ Cell package : The bare cell is packed by which packaging material, PET tube.

■ Model and tube marking : there are three lines on the cell tube as follows.

Line 1 : INR18650-25R --- cell model name

Line 2 : SAMSUNG SDI --- cell manufacturer

Line 3 : 2D51 --- date code (Capacity ; “2” is over 2.0Ah, Year, Month, Week)

■ Lot marking : There are three lines on the cell metal can as follows.

Line 1 : J5D5 --- 1st digit: Line number (“1” for cylindrical line No.1, “J” for cylindrical line No. 8)

2nd digit: Final number of Model Name (“5” is INR18650-25x)

3rd digit: Year (“D” is 2013)

4th digit: Month (“5” is May ; A is Oct., B is Nov., C is Dec)

Line 2 : 45221 --- 1st digit: Negative coater number (“7” is No. 7 coater)

2nd ~ 4th digit: Batch number

5th digit: Serial No. of assembling

Line 3 : 62F1 --- 1st digit: Date (“6” is 6th day ; 10 is A, 11 is B…)

2nd digit: Serial No. of winding in a batch

3rd digit: Reel No (“F” is F reel ; A is A reel, B is B reel, ... F is F reel)

4th digit: Winding Machine No. (“1” is No.1 winder)

Revision history

Version	Date('yr-m-d)	Changes/Author	Reason of change
1.0	'14-02-10	In-Young Jang	First version

Panasonic

Lithium Ion
NCR18650A

Features & Benefits

- High energy density
- Long stable power and long run time
- Ideal for notebook PCs, boosters, portable devices, etc.

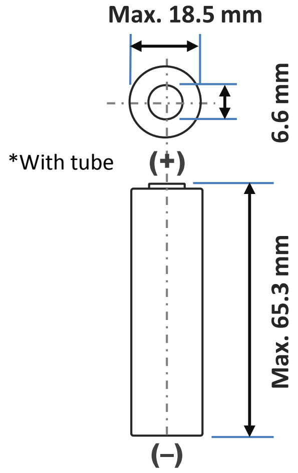
* At temperatures below 10°C, charge at a 0.25C rate.

Specifications

Rated capacity[1]	Min. 2900mAh
Capacity[2]	Min. 2950mAh Typ. 3070mAh
Nominal voltage	3.6V
Charging	CC-CV, Std. 1475mA, 4.20V, 4.0 hrs
Weight (max.)	47.5 g
Temperature	Charge*: 0 to +45°C Discharge: -20 to +60°C Storage: -20 to +50°C
Energy density[3]	Volumetric: 620 Wh/l Gravimetric: 225 Wh/kg

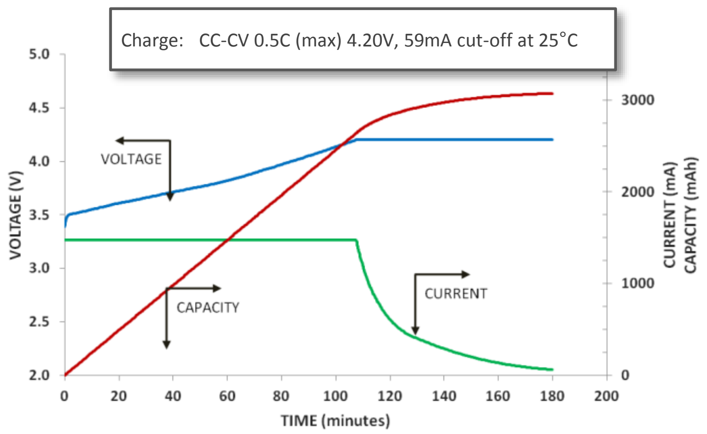
[1] At 20°C [2] At 25°C [3] Energy density based on bare cell dimensions

Dimensions

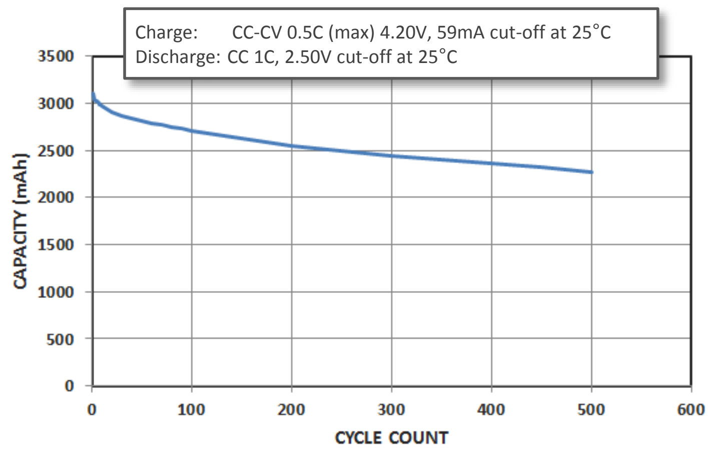


For Reference Only

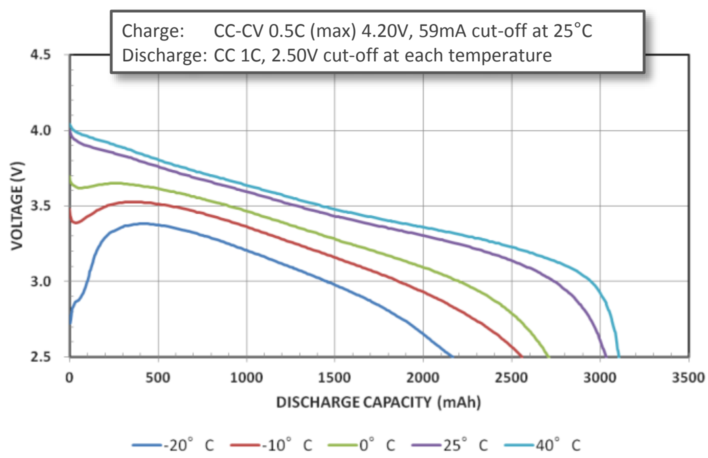
Charge Characteristics



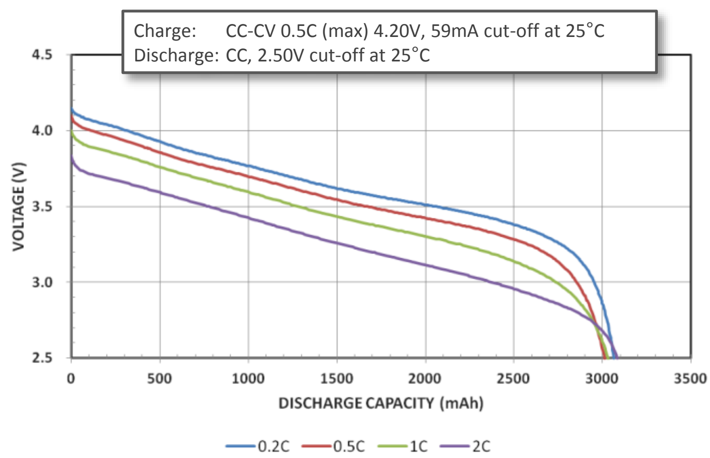
Cycle Life Characteristics



Discharge Characteristics (by temperature)



Discharge Characteristics (by rate of discharge)



The data in this document is for descriptive purposes only and is not intended to make or imply any guarantee or warranty.

Lithium Ion Manganese Cell

For all applications like pedelecs, scooters, gardening tools, household applications etc.

1. General

1.1 Scope

This specification shall be applied to lithium ion manganese rechargeable battery cells named BM18650Z3.

BM18650Z3 utilized lithium ion manganese cathode material. It brings high-power combined with high-energy and longlife performance characteristic.

1.2 Name and Code

1.2.1	Cell Name :	BM18650Z
1.2.2	Model Number:	BM18650Z3

1.3 Cell Shape and Weight

1.3.1	Cell Shape:	Cylindrical
1.3.2	Size (with plastic tube) :	
	Diameter:	18.35 mm max.
	Length:	65.1 mm max.
1.3.3	Weight:	43.6 g average

1.4 Safety Regulation

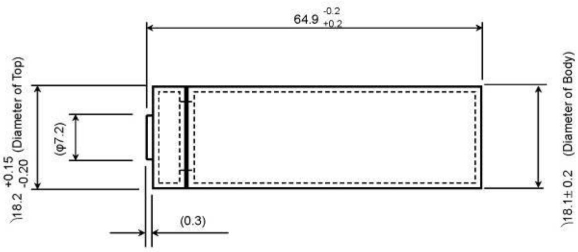
UL 1642 acquired

2. Performance

at room temperature, 2.5V cut off

Nominal Capacity (0.2ItA discharge)	2250mAh	
Rated Capacity (0.2ItA discharge)	2150mAh	minimum capacity
Capacity at (1C discharge)	2137mAh	average capacity
Capacity at (10A discharge)	2189mAh	average capacity
Nominal Voltage	3.7V	
Internal Impedance	31.5mΩ Typ.	average measured by AC1kHz

Cell Size (with plastic tube)



* Standard Charge Condition

Charge Method	: constant current, constant voltage
Charge Up Voltage	: 4.2±0.05V
Charge Current	: 2.15A
Charge Time	: 2.5h
Ambiance Temperature	: 23℃

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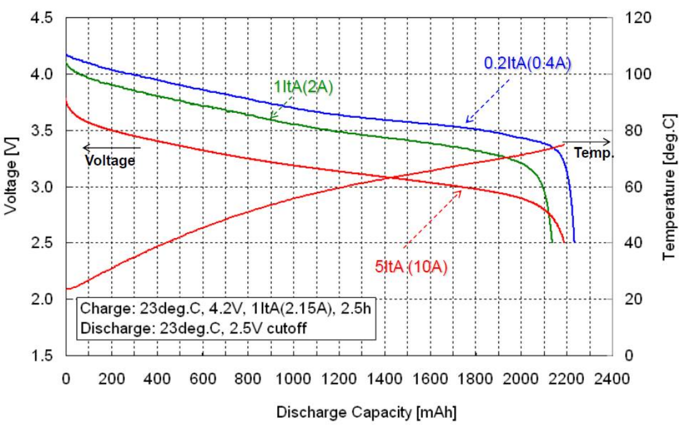
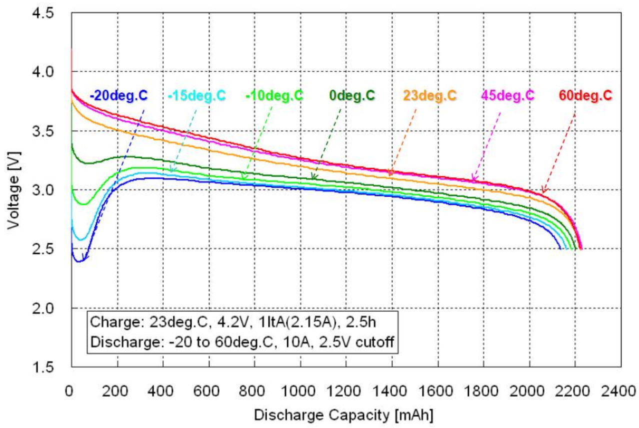
phone +49 6188 9956-0 · fax +49 6188 9956-900 · mail@bmz-gmbh.de · www.bmz-gmbh.de

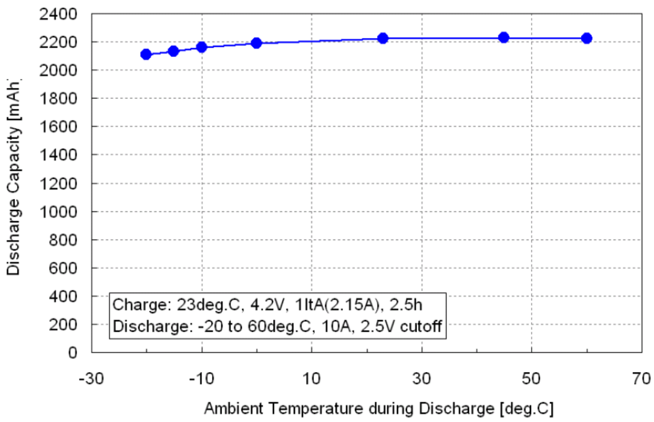
Discharge Curves



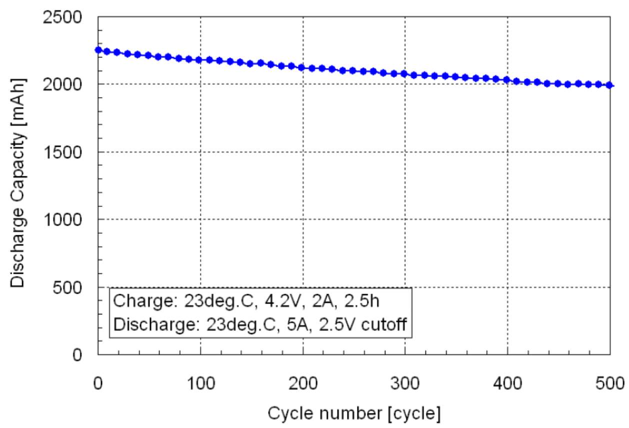
Temperature Dependence of Discharge Curves



Discharge Load Characteristics



Cycle Life Characteristics



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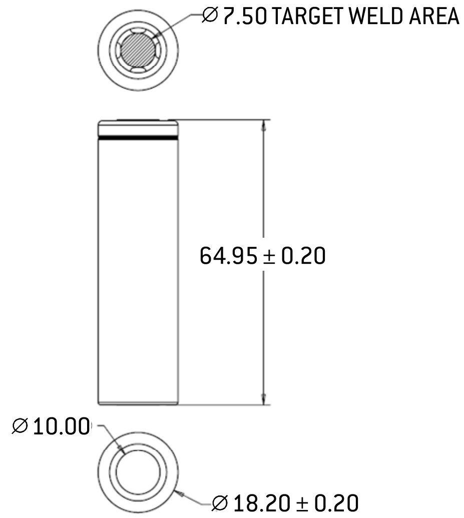
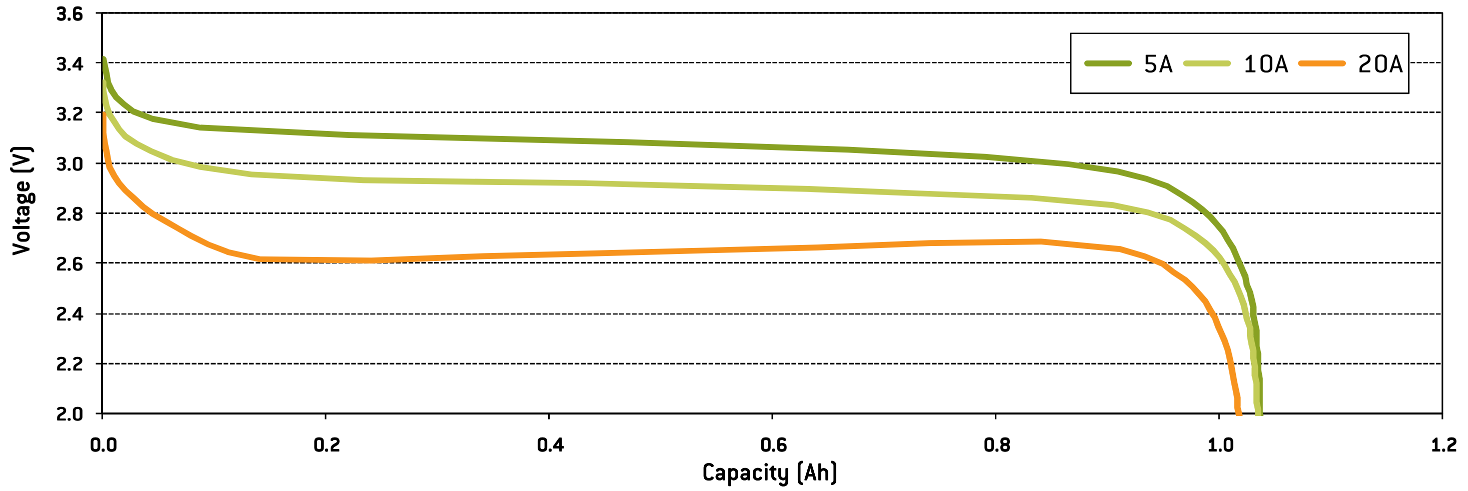
High Power Lithium Ion APR18650m1

A123Systems' lithium ion rechargeable APR18650m1 cell is capable of very high power, long cycle and storage life, and has superior abuse tolerance due to the use of patented Nanophosphate™ technology.

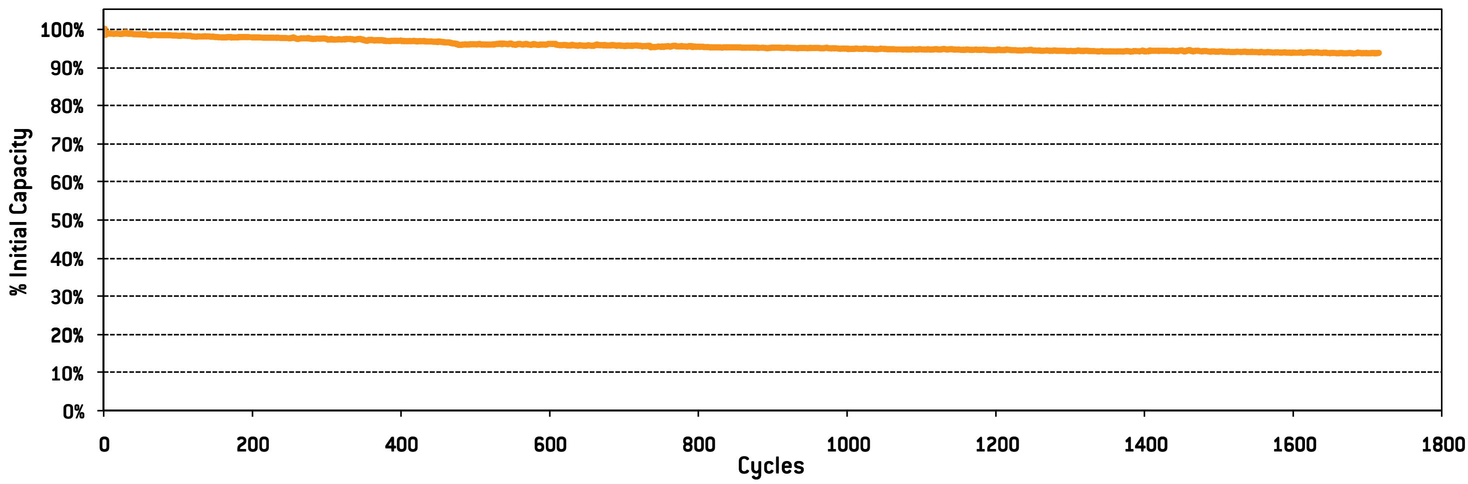
Nominal capacity and voltage	1.1Ah, 3.3 V
Recommended standard charge method	1.5A to 3.6V CCCV, 45 min
Recommended fast charge current	4A to 3.6V CCCV, 15 min
Maximum continuous discharge	30A
Cycle life at 5C discharge, 100% DOD	Over 1,000 cycles
Recommended charge and cut-off V at 25°C	3.6V to 2V
Operating temperature range	-30°C to +60°C
Storage temperature range	-50°C to +60°C
Core cell weight	39 grams



Discharge Characteristics, Room Temperature



Projected Cycle Life, 100% DOD, 1C/1C, Room Temperature



A123Systems
321 Arsenal Street, Watertown, MA 02472
www.a123systems.com

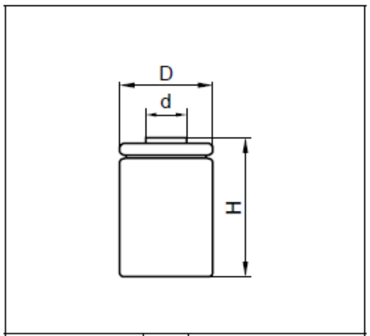
* Preliminary specifications, performance may vary depending on use conditions and application.
A123Systems makes no warranty explicit or implied with this datasheet. Contents subject to change without notice.

MD100009

Panasonic

Cell Type N-1250SCRL
Specifications

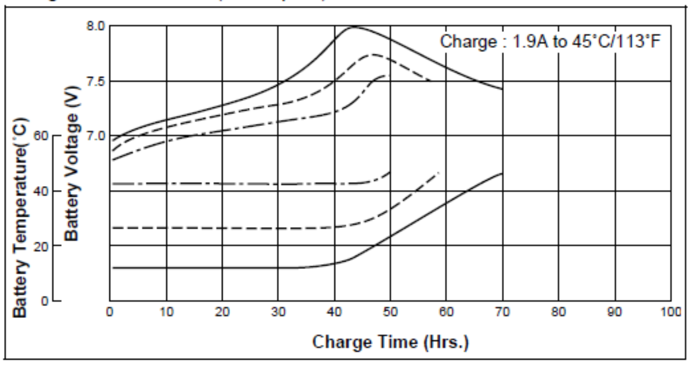
Nominal Capacity			1200mAh
Nominal Voltage			1.2V
Charging Current		Standard	125mA
		Quick	375mA
		Fast	1900mA
Charging Time		Standard	14 to 16Hrs.
		Quick	4 to 6Hrs.
		Fast	about 1Hr.
Ambient Temperature	Charge	Standard	0°C to +45°C [+32°F to 113°F]
		Quick	10°C to +45°C [+50°F to 113°F]
		Fast	5°C to +40°C [+41°F to 104°F]
	Discharge		-20°C to +60°C [-4°F to 140°F]
	Storage		-30°C to +50°C [-22°F to 122°F]
Internal Impedance (Av.) (at. 50% discharge)			5.0mΩ (at 1000Hz)
Weight			43g/1.52oz
Dimensions(D)×(H) (with tube)			$22.9^{\,0}_{\,-1} \times 34.0^{\,0}_{\,-1.2}$ mm $0.90^{\,0}_{\,-0.04} \times 1.34^{\,0}_{\,-0.05}$ inch



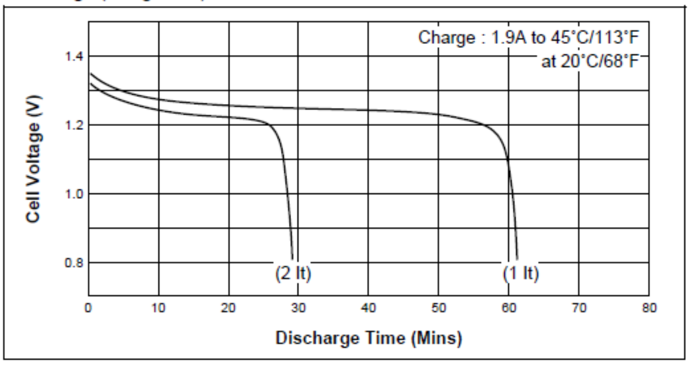
Dimensions of Bare Cell	H	$33.0^{\pm0.3}$	mm
		$1.299^{\pm0.012}$	inch
	D	$22.0^{\pm0.3}$	mm
		$0.866^{\pm0.012}$	inch
	d	10.0	mm
		0.394	inch

Typical Characteristics

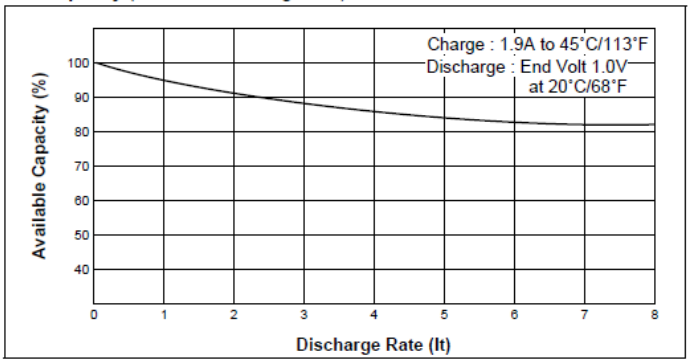
Charge Characteristics (5 cells pack)



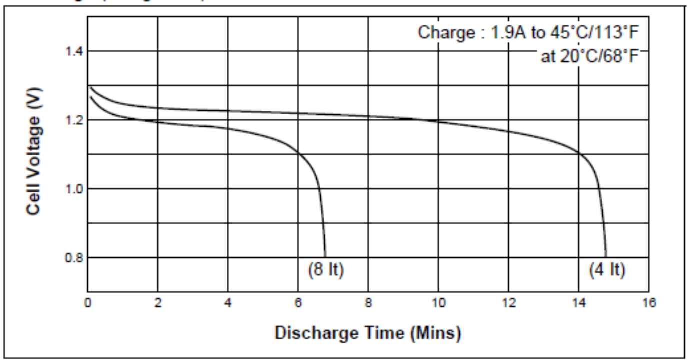
Discharge (at high rate)



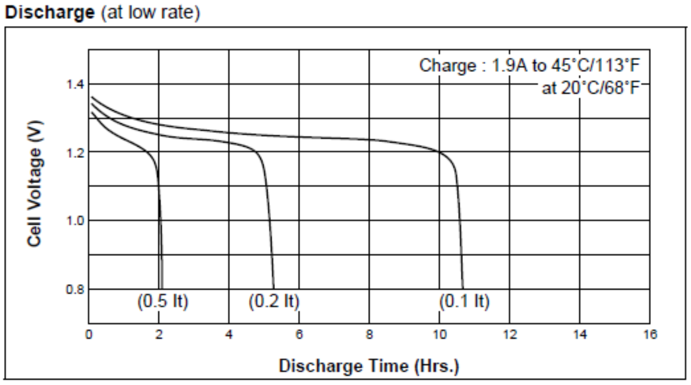
Cell Capacity (at various discharge rate)



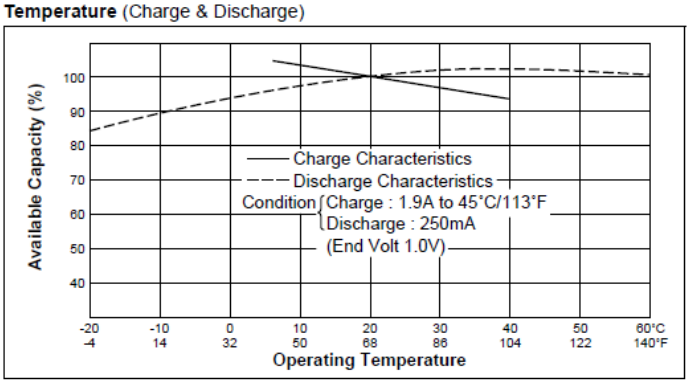
Discharge (at high rate)



Discharge (at low rate)



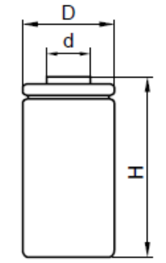
Temperature (Charge & Discharge)



Panasonic

Cell Type KR-1800SCE
Specifications

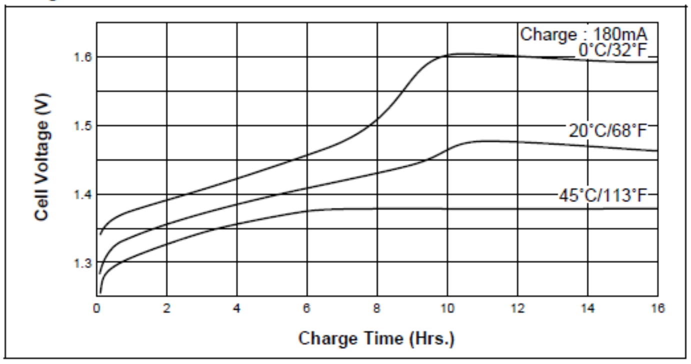
Nominal Capacity			1800mAh
Nominal Voltage			1.2V
Charging Current		Standard	180mA
		Fast	2700mA
Charging Time		Standard	14 to 16Hrs.
		Fast	about 1Hr.
Ambient Temperature	Charge	Standard	0°C to +45°C [+32°F to 113°F]
		Fast	0°C to +45°C [+32°F to 113°F]
	Discharge		-20°C to +60°C [-4°F to 140°F]
	Storage		-30°C to +50°C [-22°F to 122°F]
Internal Impedance (Av.) (at 50% discharge)			6.5mΩ (at 1000Hz)
Weight			49g/1.73oz
Dimensions(D)×(H) (with tube)			22.9 $^{0}_{-1}$ × 43.0 $^{0}_{-1.2}$ mm 0.90 $^{0}_{-0.04}$ × 1.69 $^{0}_{-0.05}$ inch



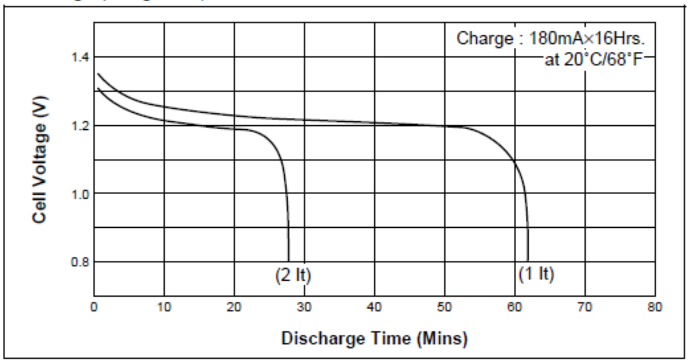
Dimensions of Bare Cell	H	42.0 $^{\pm0.3}$	mm
		1.654 $^{\pm0.012}$	inch
	D	22.0 $^{\pm0.2}$	mm
		0.866 $^{\pm0.008}$	inch
	d	10.0	mm
		0.394	inch

Typical Characteristics

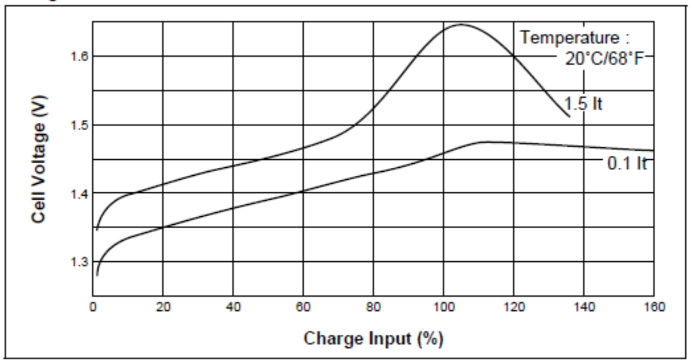
Charge



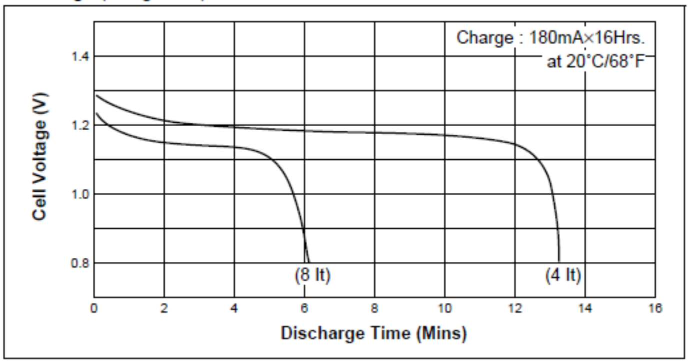
Discharge (at high rate)



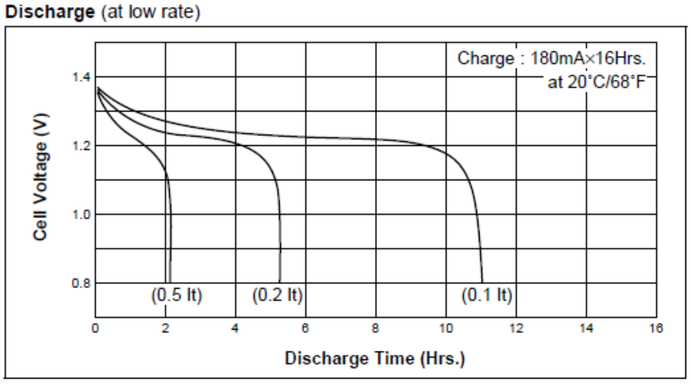
Charge



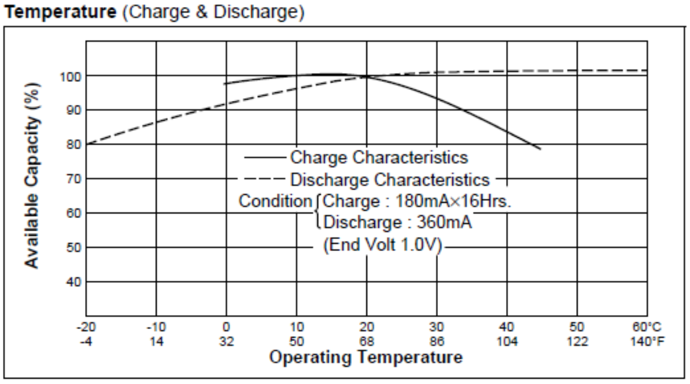
Discharge (at high rate)



Discharge (at low rate)



Temperature (Charge & Discharge)



CD120229-01

EMMERICH

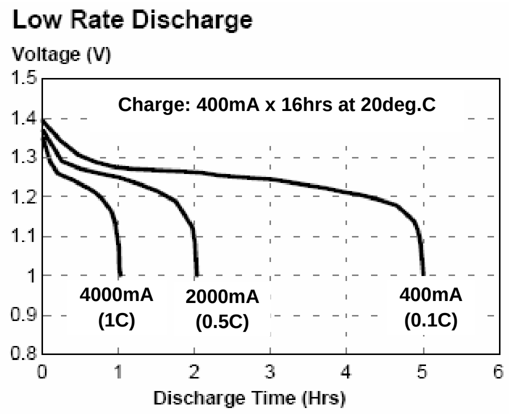
Specification for Sealed Rechargeable Nickel Metal Hydride Battery

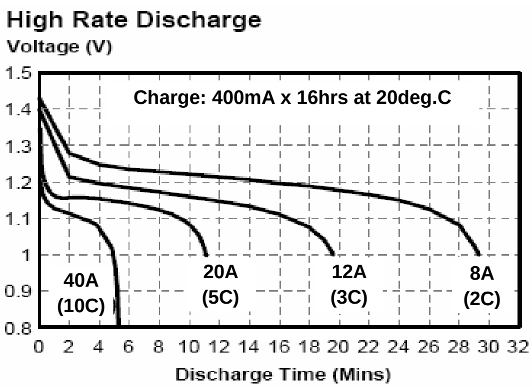
Model: EMMERICH NIMH AKKU SUB C 4000 MAH FT-1Z (255003)

Chemical System:	**Nickel Metal Hydride**	Ni-MH			
Type	**SC**	Flat Top			
Nominal Voltage	**Ultra Power**	1,2 V			
Nominal Capacity	**Low Rate - 0.1C**	4000 mAh			
Weight		66 g			
Capacity		**Charge**	**Discharge**	**Minimum**	**Typical**
	Low Rate - 0.1C	0.1C	0.2C	3900 mAh	4020 mAh
	High Rate - 1C	0.1C	1C	3510 mAh	3630 mAh
Charging		**Standard**	**Quick***	**Fast***	
	Minimum Charge	400 mA (0.1C)	400 mA (0.1C)	400 mA (0.1C)	
	Time Required (hrs)	16 hrs	16 hrs	16 hrs	
	Maximum Charge	800 mA (0.2C)	2000 mA (0.5C)	4000 mA (1C)	
	Time Required (hrs)	< 8 hrs	< 2.2 hrs	< 66 min (or - Delta V)	
	Minimum Overcharge	400 mA (0.1C)			
	Maximum Overcharge	8000 mA with cut-off control			
Maximum Discharge Current	**Continuous**	70 A			
	Momentary (1 second)	150 A			
Internal Impedance	**Typical at 1000Hz**	8 milliohms upon fully charged			
Temperature		**Storage for < 1 Month (deg.C)**	**Storage for < 1 Year (deg.C)**		
	Minimum	-20	-10		
	Maximum	40	30		
		Discharge (deg.C)	**Charge (deg.C)**		
	Minimum	-20	0		
	Maximum	50	45		
Service Life	**Standard (IEC61951-2)**	upto 500 cycles (for reference)			
Designations		**IEC 61951-2**			

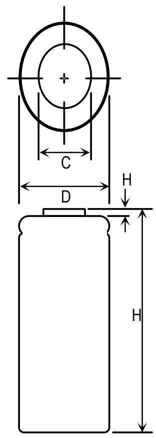
* Quick and Fast charge require cut-off control circuitry to terminate charge or switch to trickle charge when cell reaches full charge

Remark: The information contained herein is presented only as a guide for the applications of our products
Data in this specification are subjected to change without notice and become contractual only
after written confirmation by Emmerich.



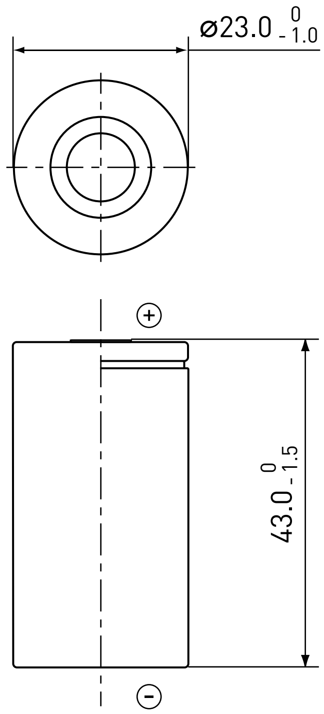


Dimensions (mm)		
D	22,5	± 0.5
C	10,0	± 0.3
H	43,5	± 0.5
H1	0,3	(REF)



HHR-260SCP/FT CYLINDRICAL SC SIZE (HR23/43)

DIMENSIONS (MM)

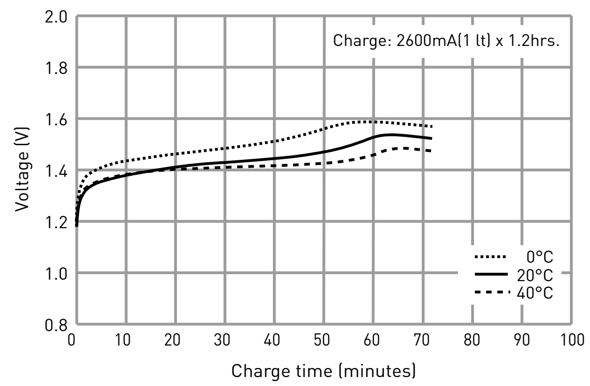


SPECIFICATIONS

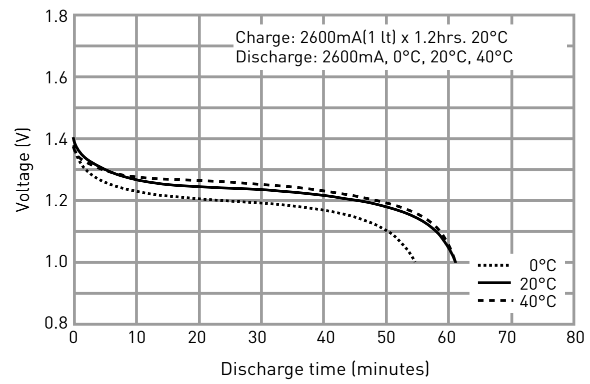
Name			HHR-260SCP/FT
Diameter (mm)			23.0 +0/-1.0
Height (mm)			43.0 +0/-1.5
Approximate weight (g)			55
Nominal voltage (V)			1.2
Discharge capacity*1		Average*2 (mAh)	2,600
		Rated/min. (mAh)	2,450
Approx. internal impedanceat 1,000Hz at charged state (mΩ)			5
Charge		Standard (mA x hrs.)	260 x 16
		Rapid*3 (mA x hrs.)	2,600 x 1.2
Ambient temperature	Charge (°C)	Standard	0 to +45
		Rapid	0 to +40
	Discharge (°C)		-10 to +65
	Storage (°C)	<1 year	-20 to +35
		<3 months	-20 to +45
		<1 month	-20 to +55

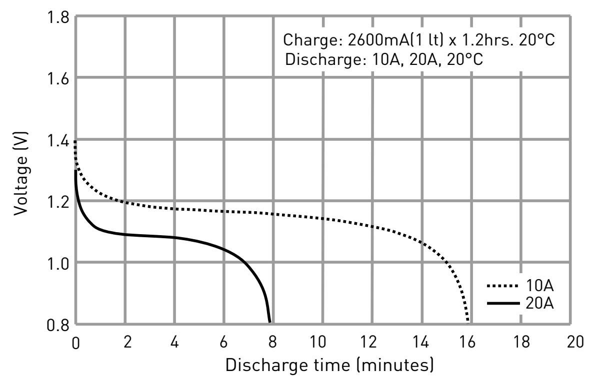
*1 After charging at 0.1It for 16 hours, discharging at 0.2It.
*2 For reference only.
*3 Need specially designed control system. Please contact Panasonic for details.

TYPICAL CHARGE CHARACTERISTICS



TYPICAL DISCHARGE CHARACTERISTICS





Battery performance and cycle life are strongly affected by how they are used. In order to maximize battery safety, please consult Panasonic when determining charge/discharge specs, warning label contents and design. The data in this document are for descriptive purposes only and are not intended to make or imply any guarantee or warranty.

NP SERIES - **NP1.2-12**

Reliability is your Security

Yuasa NP, NPC and NPH Batteries. Utilising the latest advance design Oxygen Recombination Technology, Yuasa have applied their 80 years experience in the lead acid battery field to produce the optimum design of Sealed Lead Acid batteries.

FEATURES

- Superb recovery from deep discharge.
- Electrolyte suspension system.
- Gas Recombination.
- Multipurpose: Float or Cyclic use.
- Usable in any orientation (except continuous inverted).
- Superior energy density.
- Lead calcium grids for extended life.
- Manufactured World wide.
- Application specific designs.

Technical Features

Sealed Construction
Yuasa's unique construction and sealing technique ensures no electrolyte leakage from case or terminals

Electrolyte Suspension System
All NP batteries utilize Yuasa's unique electrolyte suspension system incorporating a microfine glass mat to retain the maximum amount of electrolyte in the cells. The electrolyte is retained in the separator material and there is no free electrolyte to escape from the cells. No gels or other contaminants are added.

Control of Gas Generation
The design of Yuasa's NP batteries incorporates the very latest oxygen recombination technology to effectively control the generation of gas during normal use.

Low Maintenance Operation
Due to the perfectly sealed construction and the recombination of gasses within the cell, the battery is almost maintenance free.

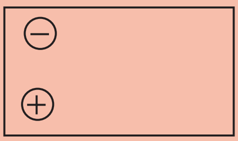
Terminals
NP batteries are manufactured using a range of terminals which vary in size and type. Please refer to details as shown.

Operation in any Orientation
The combination of sealed construction and Yuasa's unique electrolyte suspension system allows operation in any orientation, with no loss of performance or fear of electrolyte leakage. (Excluding continuous use inverted)

Valve Regulated Design
The batteries are equipped with a simple, safe low pressure venting system which releases excess gas and automatically reseals should there be a build up of gas within the battery due to severe overcharge. Note. On no account should the battery be charged in a sealed container.

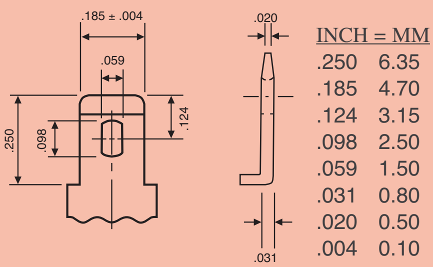
Layout

3



Terminals

Faston tab: 187 **A**



General Specifications

Nominal Capacity (Ah)	**NP1.2-12**
20hr to 1.75vpc 30°C	1.2
10hr to 1.75vpc 20°C	1.1
5hr to 1.70vpc 20°C	1
1hr to 1.60vpc 20°C	0.7
Voltage	12
Energy Density (Wh.L.20hr)	61
Specific Energy (Wh.kg.20hr)	25
Int. Resistance (m.Ohms)	110
Maximum discharge (A)	12
Short Circuit current (A)	36
Dimensions (mm)	
Length	97
Width	48
Height overall	54.5
Weight (Kg)	0.58
Terminal	A
Layout	3
Terminal Torque Nm	-

NP SERIES - **NP1.2-12**

Data Sheet

Lead Calcium Grids
The heavy duty lead calcium alloy grids provide an extra margin of performance and life in both cyclic and float applications and give unparalleled recovery from deep discharge.

Long Cycle Service Life
Depending upon the average depth of discharge, over a thousand discharge/charge cycles can be expected.

Float Service Life
The expected service life is five years in float standby applications.

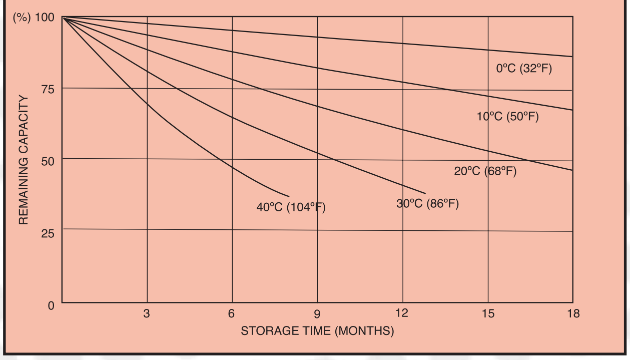
Separators
The use of the special separator material provides a very efficient insulation between plates preventing inter-plate short circuits and prohibiting the shedding of active materials.

Long shelf Life
The extremely low self discharge rate allows the battery to be stored for extended periods up to one year at normal ambient temperatures with no permanent loss of capacity.

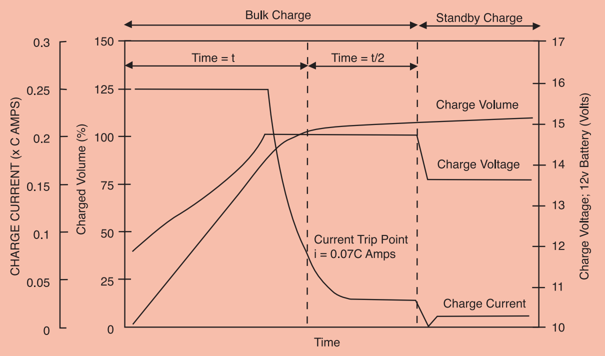
Operating Temperature Range
The batteries can be used over a broad temperature range permitting considerable flexibility in system design and location.

Charge	– 15°C to 50°C
Discharge	– 20°C to 60°C
Storage	– 20°C to 50°C (fully charged battery)

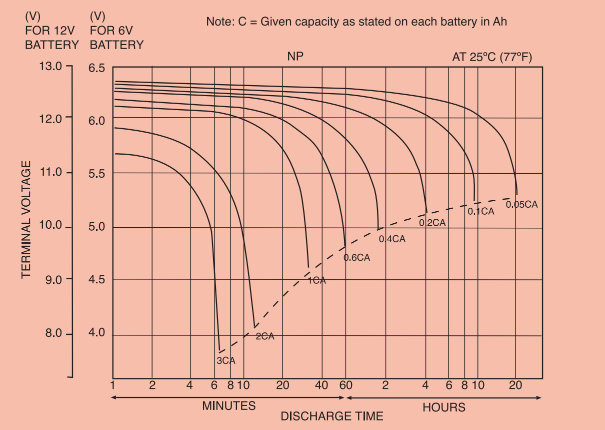
SELF DISCHARGE CHARACTERISTICS



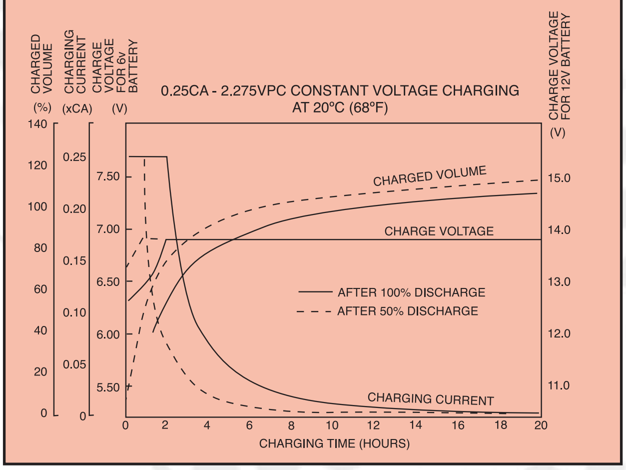
CYCLIC RECHARGE REGIME



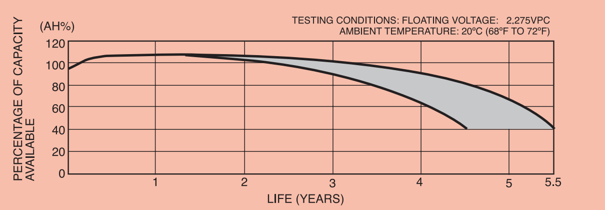
NP DISCHARGE CHARACTERISTICS CURVES AT 25ºC (77ºF)



FLOAT CHARGE CHARACTERISTICS

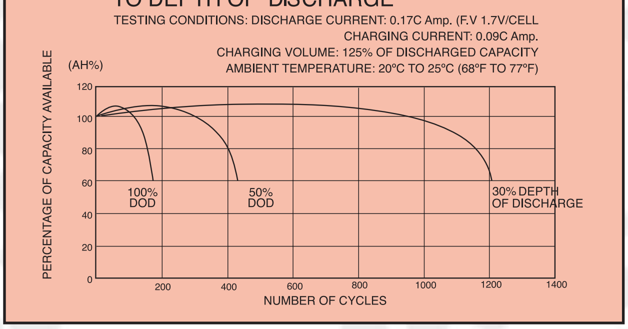


FLOAT SERVICE LIFE NP RANGE



TYPICAL DISCHARGE CHARACTERISTICS NP RANGE

CYCLE SERVICE LIFE IN RELATION TO DEPTH OF DISCHARGE



NP SERIES - **NP1.2-12**

Data Sheet

INTELLIGENT BATTERY CHARGERS

Manufactured to BS3456, IEC335, UL 1236, EN60335, CE mark to EN5008-1

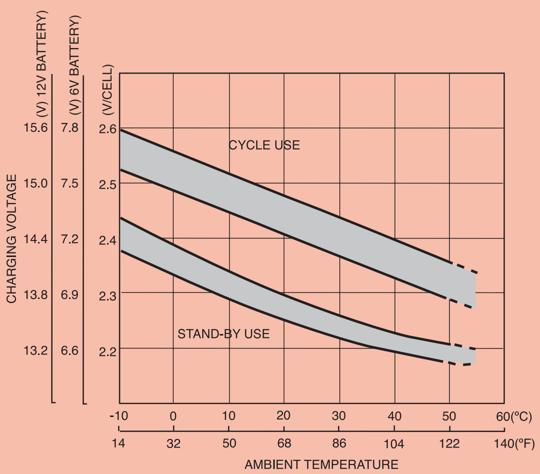
Features

Micro processor controlled
Short circuit protection
Reverse polarity protection
High temperature protection
Soft start current control
Fast constant current bulk charge
3 stage charging CI-CV-float
Constant voltage float/standby
Proportional timing
Flexibility, to match battery specification.

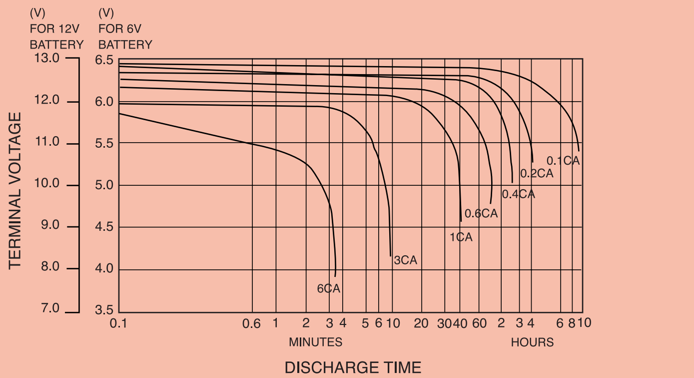
Standard Range

YCP03A12	300mA 12v
YCP03A24	300mA 24v
YCP03A6	300mA 6v
YCP06A12	600mA 12v
YCP06A6	600mA 6v
YCP1.5A12	1.5A 12v
YCP1.5A24	1.5A 24v
YCP1.5A6	1.5A 6v
YCP1A12	1A 12v
YCP1A6	1A 6v
YCP2A12	2A 12v
YCP2A24	2A 24v
YCP2A6	2A 6v
YCP3A12	3A 12v
YCP4A12	4A 12v
YCP6A12	6A 12v
YCP8A12	8A 12v
YCP10A12	10A 12v
YCP8A24	8A 24v

RELATIONSHIP BETWEEN CHARGING VOLTAGE AND TEMPERATURE



NPH DISCHARGE CHARACTERISTIC CURVES



Standard NP

Available in a wide range of sizes to suit general applications.

NPH/NPW

High performance batteries specially designed for applications requiring high rate discharge, supplying up to 50% (NPH), (NPW) more power (Watts) for short durations when compared to conventional NP models.

NPC

Specifically designed to suit the arduous requirements of cyclic applications allowing increased cycle life (at least double that of conventional types). (NPC Shortform refers)

NPL

Long Life Model also to BS6290pt4 (FR Options)
Dedicated literature available on request. (NPL Shortform refers).

Applications

Yuasa NP batteries, having excellent deep discharge recovery characteristics coupled with long life on float standby, are ideal for numerous applications in both cyclic and standby modes. For advice on the use of NP batteries in your particular application please contact our Sales Office.

Charging For Float Standby Applications

Charged at 2.275 volts per cell continuous. The battery will seek its own current level and float fully charged. However, users should be aware that when charging from fully discharged, the battery can draw an initial charge current of approximately 2cA. Care should therefore be taken to ensure that this initial charge current (if ungoverned) is within the output capability of the equipment. Final charge current at 2.275 volts per cell is typically between 0.0005cA to 0.004cA.

Charging For Cyclic Applications

See cyclic recharge regime graph.

CAUTION

- Do not Short Circuit
- Do not charge in a sealed container
- Service life and operational characteristics will be affected by temperature
- AC Ripple reduces service life.

YUASA

Yuasa Battery Sales (UK) Ltd
Unit 22 Rassau Industrial Estate
Ebbw Vale, Gwent, NP23 5SD
Tel: 08708 500312 Fax: 08708 500317
E-mail: enquiries@yuasa-sales.co.uk

Registered number 1548820

Cat. No.	NP1.2-12 February 07

E&O.E.

Distributed by

NP Baureihe – *Series*

Ventilgesteuerte Bleiakkumulatoren

Valve Regulated Lead-Acid Batteries

YUASA

YUASA BATTERY (EUROPE) GmbH

YUASA

Ventilgesteuerte Bleisäureakkumulatoren der Baureihe NP

Valve Regulated Lead-Acid Batteries NP

Yuasa als der in Europa marktbeherrschende Hersteller von wartungsfreien stationären Industriebatterien hat die Baureihe NP, deren Produktion im letzten Jahrzehnt bei über 40 Millionen Einheiten lag, technisch in betriebs- und zuverlässigkeitsbestimmenden Eigenschaften permanent verbessert, so daß der Anwender ein absolut ausgereiftes und kommerziell breit eingeführtes Produkt erwirbt, das in einer Vielzahl von Anwendungen seine Zuverlässigkeit bewiesen hat.

Yuasa as leading manufacturer of valve regulated lead-acid batteries has been improving all properties determining reliability and operational performance. The effect is that the end-user acquires a fully mature and commercially accepted product, which has proved its reliability in many various applications.

Allgemeine Produktmerkmale – *General Features*

- Lebensdauer: 3-5 Jahre nach Eurobat
  Design life: 3-5 years according to Eurobat
- NP-Batterien können dauerhaft in Seitenlage betrieben werden
  NP batteries can permanently be operated in any orientation excluding continuous use inverted.
- Schlag- und bruchfestes Kunststoffgehäuse aus ABS
  Mechanically strong ABS - container
- FR-Gehäusematerial auf Wunsch schwer entflammbar gemäß UL 94 VO, entsprechend EN 60707
  Container material for FR batteries on special request is extremely flame-retardant according to UL 94 VO, equivalent to EN 60707
- Fertigung der NP Batterien gemäß EN ISO 9001:2000 Qualitätsmanagementsystem und EN ISO 14001:2000 Umweltmanagementsystem
  Manufacture of NP batteries according to EN ISO 9001:2000 Quality Management Systems and EN ISO 14001:2000 Environment Management Systems
- Verlängerung der Gebrauchsdauer aufgrund einer speziellen Legierung der positiven Platte
  Extension of service life by means of a special alloy
- VdS/UL Zulassungen
  Certified by VdS and Underwriters Laboratories
- Temperaturbereiche: Aufladung: -15° C bis +50° C
  Entladung: -15° C bis +60° C
  Lagerung: -20° C bis +50° C
  Temperature ranges: Charging: -15° C up to +50° C
  Discharging: -15° C up to +60° C
  Storage: -20° C up to +50° C

Besondere Produktmerkmale – *Particular Features*

- Ventilgesteuerte Konstruktion, nahezu 100%ige Sauerstoffrekombination bei jedem Aufladevorgang
  Valve regulated design with nearly 100% gas recombination during float charging
- Elektrolyt in Glasfaservlies gebunden (AGM=Absorbing GlassMatt Technology)
  AGM = Absorbing GlassMatt technology in which the electrolyte is fully absorbed
- Kein Auffüllen des Elektrolyts notwendig
  No topping up of electrolyte necessary
- Korrosionsbeständige Hochleistungsgitterplatten mit Blei-Kalzium Legierung
  High current drain grid being resistant to corrosion by virtue of a lead-calcium alloy

- Weiter Betriebstemperaturbereich bei entsprechender temperaturabhängiger Spannungskompensation
  Wide range of operating temperatures with temperature compensated charging
- Sehr gute Ladeeffizienz
  Very good charging efficiency
- Kein Gefahrgut gemäß IATA
  Classified as "non-spillable" and therefore exempt from IATA Dangerous Goods Regulations
- Konformität zu EN 61056
  Conforming to EN 61056
- Hohe Lebensdauer bei geringer Selbstentladung, 3% pro Monat bei 20° C
  Extended shelf life at low self-discharge level approximately 3% per month at 20° C

Allgemeine Spezifikation der Baureihe NP – *NP Series General Specifications*

Batterie-Type Battery Type	FR Option FR Option	Nenn-spannung [V] Nominal Voltage [V]	Kapazität 20 h. 1,75V Capacity 20 h. 1,75V	Kapazität 10 h. 1,75V Capacity 10 h. 1,75V	Abmessungen/ Dimensions [mm]			Gewicht [kg] Weight [kg]	Layout Layout	Pol-Typ Terminal	Innenwider-stand mΩ Internal Re-sistance mΩ	Maximaler Entladestrom [A] Maximum Discharge Current [A]	Kurzschlussstrom Ik [A] gem IEC 896-2 Short Circuit Current Ik [A] acc. to IEC 896-2
					Länge/ Length	Breite/ Width	Höhe/ Height						
NP1-6	x	6	1	0,9	51	42,5	54,5	0,25	5	A	179	7	36
NP1.2-6		6	1,2	1,1	97	25	54,5	0,31	1	A	147	8,4	44
NP3-6		6	3	2,8	134	34	64	0,57	1	A	59	21	109
NP4-6		6	4	3,7	70	47	105,5	0,85	5	A	44	28	145
NP7-6	x	6	7	6,5	151	34	97,5	1,35	1	A	25	49	254
NP10-6*	x	6	10	9,3	151	50	97,5	1,93	1	A	18	70	363
NP12-6*		6	12	11,2	151	50	97,5	2,05	1	D	15	75	435
NP0.8-12	x	12	0,8	0,7	96	25	61,5	0,35	7	E	445	5,6	29
NP1.2-12*	x	12	1,2	1,1	97	48	54,5	0,57	3	A	293	8,4	44
NP2-12	x	12	2	1,8	150	20	89	0,70	8	B	161	14	80
NP2.3-12*		12	2,3	2,1	178	34	64	0,94	1	A	155	16,1	83
NP3.2-12	x	12	3,2	3,0	134	67	64	1,17	3	A	111	22,4	116
NP4-12	x	12	4	3,7	90	70	106	1,70	1	A	89	28	145
NP7-12*	x	12	7	6,5	151	65	97,5	2,65	4	A	51	49	254
NP7-12L	x	12	7	6,5	151	65	97,5	2,65	4	D	51	49	254
NP12-12*	x	12	12	11,2	151	98	97,5	4,09	4	D	30	84	435
NP17-12I*	x	12	17	14,0	181	76	167	5,97	2	C	20	119	631
NP24-12I*	x	12	24	22,3	166	175	125	8,92	2	C	15	168	871
NP38-12I*	x	12	38	35,4	197	165	170	13,93	2	C	9	266	1.379
NP65-12I*	x	12	65	60,5	350	166	174	22,82	2	C	5	455	2.395

* mit VdS-Zulassung
* *with VdS-approval*

FR = schwer entflammbarer Container
FR = flame retardant container

Anwendungsbereiche

- Unterbrechungsfreie Stromversorgung (USV)
- Telekommunikation
- Feueralarm- und Sicherheitssysteme
- Medizinische Geräte
- Photovoltaische Anwendungen
- Steuer- und Regelungssysteme
- Elektronische Testgeräte
- Geophysikalische Geräte
- Marine Ausrüstungen – Bahn

Main Fields of Application

- *Uninterruptible Power Supply (UPS)*
- *Telecommunication*
- *Fire alarm and security systems*
- *Medical appliance*
- *Solar applications*
- *Electronic test equipment*
- *Electronic measuring devices*
- *Geophysical devices*
- *Marine equipment – Railway*

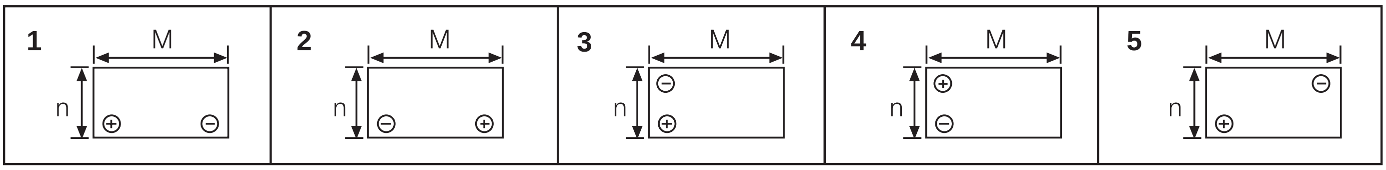
Empfohlene Entladeschlußspannung
Recommended Cut-off Voltage

Entladestrom *Discharge Current*	Entladeschlußspannung pro Zelle (V/Zelle) *Cut-off Voltage/cell*
≦ 0,10 CA	1,75 V/Zelle *V/cell*
0,17CA	1,70 V/Zelle *V/cell*
0,26 CA	1,67 V/Zelle *V/cell*
0,60 CA	1,60 V/Zelle *V/cell*
3 CA	1,50 V/Zelle Entladetiefe beeinträchtigt die Lebensdauer *V/cell Depth of discharge detrimental to service life*

Top-Charging-Empfehlungen
Top-Charging-Recommendation

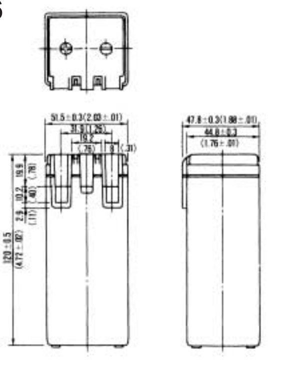
Batteriealter Lagerzeit *Battery Age Storagetime*	Top-Charging Empfehlung *Top-Charging Recommendation*
bis 6 Monate nach Herstellung *up to 6 months after date of manufacture*	4 – 6 Std. mit 0,1 C Konstantstrom oder 15 bis 20 Stunden mit Konstantspannung 2,4V/Zelle *4 – 6 hours at 0,1 C constant current or 15 – 20 hours at constant voltage 2,4V/cell* länger als 72 Std. mit Konstantspannung 2,275 V/Zelle *more than 72 hours at constant voltage 2,275 V/cell*
bis 12 Monate nach Herstellung *up to 12 months after date of manufacture*	8 –10 Std. mit 0,1C Konstantstrom oder 20 – 24 Stunden mit Konstantspannung 2,4 V/Zelle *8 – 10 hours at 0,1 C constant current or 20 to 24 hours at constant voltage 2,4V/cell* 48 – 144 Std. mit Konstantspannung 2,35 V/Zelle *48 – 144 hours at constant voltage 2,35 V/cell*

Position der Batteriepole – *Terminal Location*



Abmessungen – *Dimensions*

6



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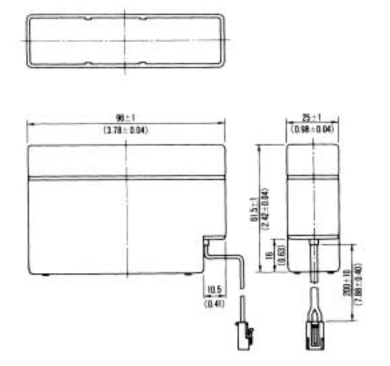

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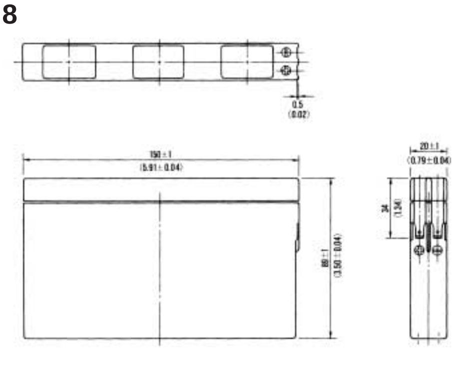
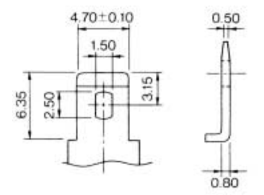
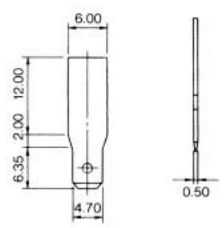


Poltypen – *Terminals*

A

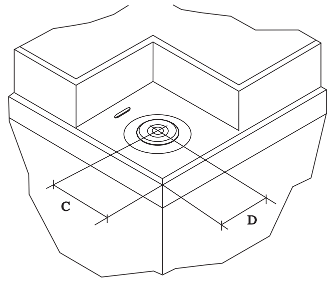


B

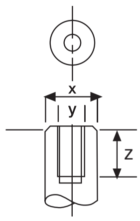


C

Polabstände – *Terminal Design*

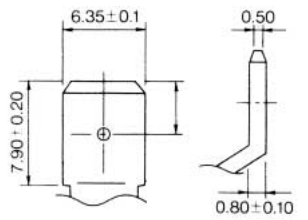


NP	Gewinde/ *Thread*	C	D
17 – 12 I	M5	12	43
24 – 12 I	M5	12	40
38 – 12 I	M5	22	19
65 – 12 I	M6	23	30



x	y	z	Nm
17 mm	M5 x 10		2-3
20 mm	M6 x 16		4-5.5

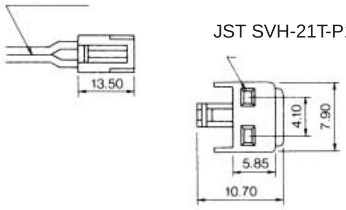
D



E

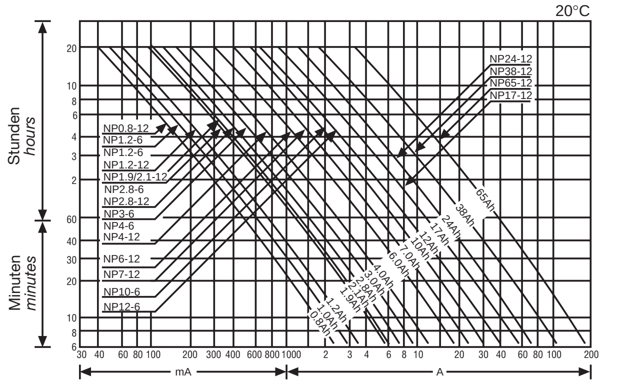
Kabel: AWG # 20 UL 1007

JST SVH-21T-P1.1

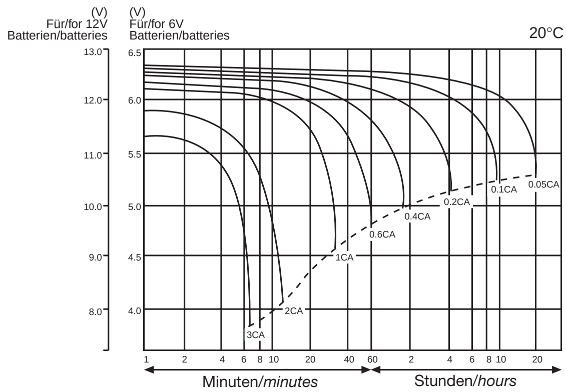


Spezifikationen – *Specifications*

Entladekapazität
Capacity Selection Chart



NP Entladecharakteristik bei 20°C
NP Discharge Characteristic Curves at 20°C



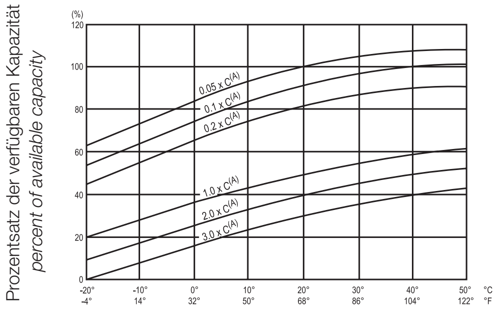
Entladestrom (Ampère) bei vorgegebener Entladerate
Discharge current (Ampères) at stipulated discharge rates

20 Std./*hrs.* Kapazität *capacity*	0,05C	0,1C	0,2C	0,4C	0,6C	1C	2C	3C
0,8 Ah	0,04 A	0,08	0,16	0,32	0,48	0,8	1,6	2,4
1	0,05	0,10	0,20	0,40	0,60	1	2	3
1,2	0,06	0,12	0,24	0,48	0,72	1,2	2,4	3,6
2	0,10	0,20	0,40	0,80	1,20	2	4	6
2,1	0,105	0,21	0,42	0,84	1,26	2,1	4,2	6,3
2,3	0,115	0,23	0,46	0,92	1,38	2,3	4,6	6,9
2,8	0,14	0,28	0,56	1,12	1,68	2,8	5,6	8,4
3	0,15	0,30	0,60	1,20	1,80	3	6	9
4	0,20	0,40	0,80	1,60	2,40	4	8	12
7	0,35	0,70	1,40	2,80	4,20	7	14	21
10	0,50	1,0	2,0	4,0	6,0	10	20	30
12	0,60	1,20	2,40	4,80	7,20	12	24	36
17	0,85	1,70	3,40	6,80	10	17	34	51
24	1,20	2,40	4,80	9,60	14	24	48	72
38	1,90	3,80	7,60	15	22	38	76	114
65	3,25	6,50	13	26	39	65	130	195

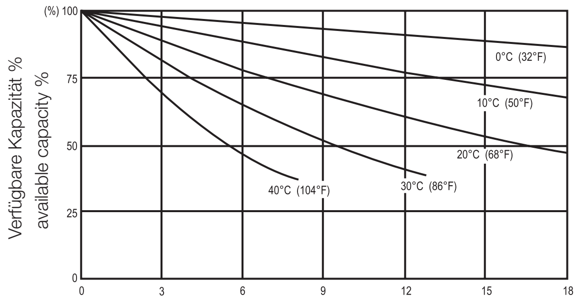
Konstant-Wattentnahme bei vorgegebener Entladeschlußspannung: Watt/Ah/Zelle bei 20° C
Power drain over time at stipulated cut-off voltages: Watt/Ah/Cell at 20° C

Entladezeit/ *Discharge time* V/Zelle *V/cell*	5 M	10 M	15 M	20 M	25 M	30 M	35 M	40 M	45 M	60 M	2 Std. *2 hrs.*	3 Std. *3 hrs.*	5 Std. *5 hrs.*
1,6	5,421	3,884	3,074	2,554	2,211	1,943	1,767	1,621	1,490	1,201	0,721	0,524	0,346
1,63	5,303	3,864	3,016	2,533	2,191	1,938	1,747	1,611	1,471	1,198	0,716	0,521	0,343
1,65	5,268	3,806	2,984	2,513	2,178	1,914	1,743	1,602	1,458	1,194	0,713	0,518	0,341
1,67	5,173	3,740	2,952	2,503	2,159	1,895	1,728	1,589	1,445	1,186	0,708	0,515	0,339
1,69	5,056	3,712	2,922	2,477	2,128	1,881	1,705	1,580	1,432	1,174	0,704	0,513	0,337
1,7	4,945	3,632	2,907	2,467	2,116	1,872	1,702	1,567	1,422	1,171	0,700	0,511	0,335
1,75	4,692	3,551	2,822	2,372	2,048	1,819	1,648	1,517	1,373	1,151	0,682	0,496	0,326
1,8	4,493	3,389	2,559	2,272	1,964	1,754	1,579	1,444	1,318	1,086	0,658	0,478	0,314
1,85	4,130	3,163	2,526	2,144	1,857	1,655	1,482	1,350	1,240	1,023	0,622	0,459	0,300

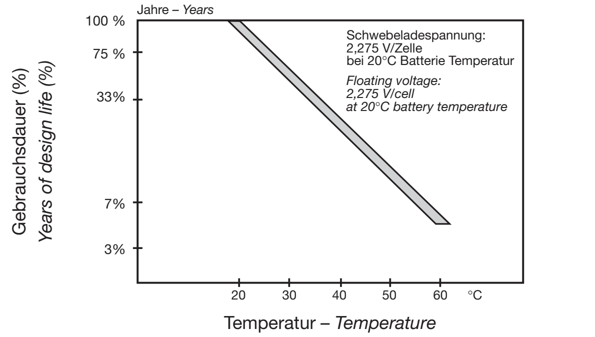
Temperatureinfluß auf die Batteriekapazität
Influence of temperature on battery capacity



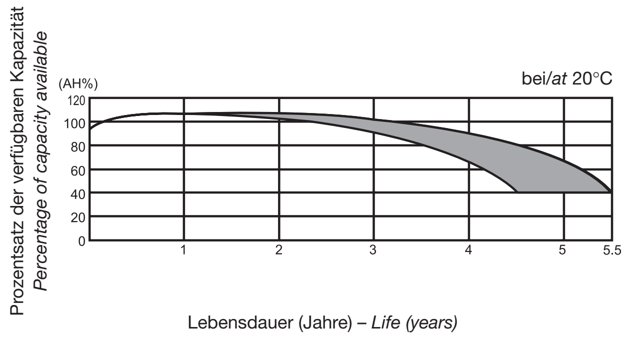
Selbstentladeverhalten bei verschiedenen Temperaturen
NP Self Discharge Characteristics at various temperatures



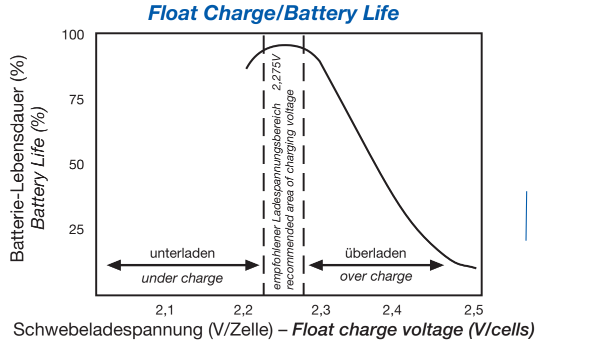
Temperatur/Gebrauchsdauercharakteristik der NP Batterien
Temperature/Life Characteristics of NP Batteries



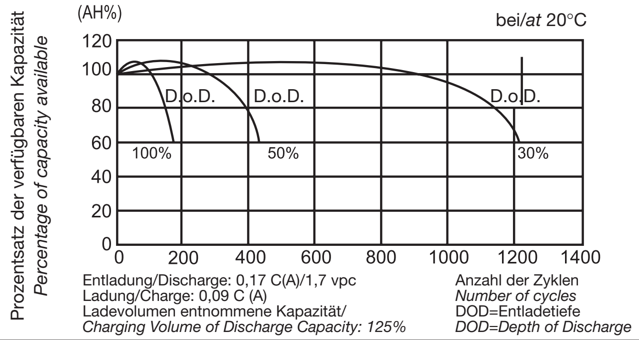
Gebrauchsdauer im Schwebeladebetrieb (2,275 V/Zelle)
Service Life – Float Charge (2,275 V/cell)



Gebrauchsdauer in Abhängigkeit der Schwebeladespannungsvariabilität
Float Charge/Battery Life



Anzahl der Zyklen im Verhältnis zur Entladetiefe
Cyclic Service Life in Relation to Depth of Discharge



YUASA NP Serie, geprüfte Qualität

EN ISO 9001:2000 – Batterien aus unserer europäischen Produktion werden nach Qualitätsstandard EN ISO 9001:2000 hergestellt

VdS-Zulassung – NP Akkumulatoren sind VdS geprüft

IEC 61056/ IEC 60896-2 – Internationaler Standard für ventilgesteuerte Bleiakkumulatoren

DIN-Normen – Wie DIN-43534; Akkumulatoren mit Gitterplatten und festgelegtem Elektrolyt DIN-Kurzzeichen: GiV

UL-Anerkennung – Die Baureihe NP ist im UL-Sicherheitsstandard unter MH 12970 und MH 28018 registriert

IATA – Yuasa NP Batterien sind kein Gefahrengut gemäß IATA. Sie sind als auslaufsicher klassifiziert.

YUASA NP Series Standardized Quality

EN ISO 9001:2000 – *Batteries from our European factory are manufactured in accordance with EN ISO 9001:2000*

VdS Approval – *NP batteries are approved by VdS*

IEC 61056/ IEC 60896-2 – *In accordance with International Standard for valve regulated lead-acid batteries*

DIN Standards – *Like DIN-43534, accumulators with grid plates and electrolyte absorbing glass-matt*

UL-Approval – *Yuasa NP-series batteries are approved and listed in UL Directory with file no. MH 12970 and MH 28018.*

IATA – *Yuasa NP series batteries are exempt from IATA Dangerous Goods Regulations. They are classified as non-spillable.*

NP Konstantleistungsentnahme (Watt/Zelle) bei 1,60 V/Zelle Entladeschlußspannung bei 20°C
NP Constant Power Discharge (Watt/cell) to 1.60 V/cell cut-off voltage at 20°C

	Autonomie in Minuten *Autonomy in minutes*								Autonomie in Stunden *Autonomy in hours*						
Typ – *Type*	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**1**	**2**	**3**	**5**	**8**	**10**	**20**
NP 1-6	5,4	3,9	3,0	2,5	2,2	1,9	1,7	1,6	1,5	1,2	0,7	0,5	0,35	0,29	0,21	0,1
NP 1.2-6 / NP 1.2-12	6,5	4,7	3,6	3,0	2,6	2,3	2,1	1,9	1,8	1,4	0,9	0,6	0,4	0,3	0,25	0,12
NP 3-6	16,3	11,7	9,22	7,66	6,63	5,83	5,3	4,86	4,47	3,5	2,15	1,57	1,04	0,87	0,63	0,3
NP 4-6 / NP 4-12	21,7	15,5	12,3	10,2	8,8	7,8	7,1	6,5	5,9	4,8	2,9	2,1	1,4	0,96	0,75	0,4
NP 7-6 / NP7-12	37,9	27,2	21,5	17,9	15,5	13,6	12,4	11,3	10,4	8,4	5,0	3,7	2,4	1,56	1,27	0,71
NP 10-6	54,2	38,9	30,7	25,5	22,1	19,4	17,7	16,2	14,9	12	7,2	5,2	3,4	2,5	1,85	1,2
NP 12-6 / NP 12-12	65,1	46,6	36,9	30,6	26,5	23,3	21,5	19,4	17,8	14,4	8,6	6,3	4,1	2,7	2,25	1,34
NP 0.8-12	4,3	3,1	2,4	2	1,8	1,5	1,4	1,3	1,2	1,0	0,6	0,4	0,3	0,18	0,15	08
NP 2-12	10,8	7,7	6,1	5,1	4,5	3,9	3,5	3,3	2,9	2,4	1,5	1,2	0,63	0,48	0,37	0,2
NP 2.3-12	12,5	9,0	7,0	5,8	5,3	4,5	3,9	3,7	3,4	2,7	1,6	1,3	0,7	0,5	0,4	0,2
NP 3.2-12	17,4	12,4	9,8	8,1	7,0	6,3	5,7	5,2	4,8	3,8	2,3	1,7	1,1	0,78	0,58	0,33
NP 17-12I	92,1	66,1	52,2	43,4	37,6	33,0	30,0	27,5	25,4	20,4	12,2	8,8	5,9	4,1	3,1	1,74
NP 24-12I	130	93,2	73,8	61,3	53,1	46,6	42,4	38,9	35,8	28,8	17,3	12,6	8,3	5,76	4,53	2,5
NP 38-12I	206	148	117	97,1	84,1	73,8	67,1	61,6	56,6	45,6	27,4	19,9	13,1	9,22	7,9	3,84
NP 65-12I	352	253	200	166	144	126	115	105	96,9	78,1	46,9	34,1	22,5	15,7	12,0	6,5

NP Konstantleistungsentnahme (Watt/Zelle) bei 1,65 V/Zelle Entladeschlußspannung bei 20°C
NP Constant Power-Discharge (Watt/cell) to 1.65 V/cell cut-off voltage at 20°C

	Autonomie in Minuten *Autonomy in minutes*								Autonomie in Stunden *Autonomy in hours*						
Typ – Type	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**1**	**2**	**3**	**5**	**8**	**10**	**20**
NP 1-6	5,3	3,8	3,0	2,5	2,2	1,9	1,7	1,6	1,5	1,2	0,7	0,5	0,35	0,27	0,2	0,1
NP 1.2-6 / NP 1.2-12	6,3	4,6	3,6	3,0	2,6	2,2	2,0	1,9	1,7	1,4	0,9	0,6	0,4	0,28	0,24	0,12
NP 3-6	15,8	11,4	8,95	7,54	6,53	5,74	5,23	4,81	4,37	3,58	2,14	1,55	1,02	0,81	0,6	0,3
NP 4-6 / NP 4-12	21,0	15,2	12,0	10,1	8,7	7,7	7,0	6,4	5,8	4,8	2,9	2,1	1,4	0,93	0,74	0,4
NP 7-6 / NP 7-12	36,9	26,6	20,9	17,6	15,2	13,4	12,2	11,2	10,2	8,3	5,0	3,7	2,4	1,55	1,27	0,7
NP 10-6	52,7	38,1	29,8	25,2	21,8	19,1	17,4	16	14,6	11,9	7,1	5,2	3,4	2,3	1,83	11
NP 12-6 / NP 12-12	63,2	45,6	35,8	30,0	26,0	23,0	20,9	19,2	17,5	14,3	8,5	6,2	4,1	2,7	2,21	1,26
NP 0.8-12	4,2	3,0	2,4	2,0	1,8	1,5	1,4	1,3	1,2	1,0	0,6	0,4	0,3	0,18	0,15	0,08
NP 2-12	10,5	7,5	6,0	5,0	4,5	3,9	3,5	3,2	2,9	2,4	1,5	1,2	0,63	0,46	0,37	0,2
NP 2.3-12	12,0	8,8	6,9	5,8	5,3	4,5	3,9	3,6	3,4	2,7	1,6	1,3	0,72	0,5	0,4	0,25
NP 3.2-12	16,9	12,1	9,5	8,0	6,9	6,2	5,6	5,1	4,7	3,8	2,3	1,7	1,1	0,74	0,58	0,33
NP 17-12I	89,6	64,6	50,7	42,7	36,8	32,5	29,5	27,1	24,8	20,2	12,1	8,8	5,8	4,9	3,1	1,71
NP 24-12I	126	91,2	71,5	60,2	52,0	45,8	41,7	38,3	35,1	28,5	17,1	12,5	8,2	5,6	4,4	2,4
NP 38-12I	200	144	113	99,6	82,5	72,7	66,2	60,7	55,5	45,2	27,1	19,7	13,0	8,9	7,0	3,8
NP 65-12I	343	247	194	163	141	125	114	104	94,8	77,3	46,3	33,7	22,2	15,0	11,9	6,5

NP Konstantleistungsentnahme (Watt/Zelle) bei 1,70 V/Zelle Entladeschlußspannung bei 20°C
NP Constant Power-Discharge (Watt/cell) to 1.70 V/cell cut-off voltage at 20°C

Autonomie in Minuten / *Autonomy in minutes* — Autonomie in Stunden / *Autonomy in hours*

Typ – Type	5	10	15	20	25	30	35	40	45	1	2	3	5	8	10	20
NP 1-6	4,9	3,69	2,9	2,5	2,1	1,9	1,7	1,6	1,4	1,2	0,7	0,5	0,3	0,22	0,18	0,1
NP 1.2-6 / NP 1.2-12	5,9	4,4	3,5	3,0	2,5	2,2	2,0	1,9	1,7	1,4	0,8	0,6	0,4	0,26	0,22	0,12
NP 3-6	14,8	10,9	8,72	7,4	6,35	5,62	5,11	4,7	4,27	3,51	2,1	1,53	1,0	0,66	0,54	0,3
NP 4-6 / NP 4-12	19,8	14,5	11,6	9,9	8,5	7,5	6,8	6,3	5,7	4,7	2,8	2,0	1,3	0,88	0,72	0,4
NP 7-6 / NP 7-12	34,6	25,4	20,3	17,3	14,8	13,1	11,9	11,0	9,9	8,2	4,9	3,6	2,3	1,54	1,27	0,7
NP 10-6	49,5	36,3	29,1	24,7	21,2	18,7	17,0	15,7	14,2	11,7	7,0	5,1	3,3	2,2	1,8	1,0
NP 12-6 / NP 12-12	59,3	43,6	34,9	29,6	25,4	22,5	20,4	18,8	17,1	14,1	8,4	6,1	4,1	2,64	2,18	1,18
NP 0.8-12	4,0	2,9	2,3	2,0	1,7	1,5	1,4	1,3	1,1	0,9	0,6	0,4	0,3	0,18	0,15	0,08
NP 2-12	10,0	7,63	5,8	4,9	4,5	3, 8	3,4	3,1	2,8	2,3	1,4	1,2	0,63	0,44	0,37	0,2
NP 2.3-12	11,4	8,3	6,7	5,7	5,3	4,38	3,8	3,5	3,29	2,6	1,5	1,3	0,7	0,5	0,4	0,23
NP 3.2-12	15,9	11,6	9,4	7,9	6,8	6,0	5,4	5,0	4,6	3,7	2,2	1,6	1,0	0,74	0,58	0,32
NP 17-12I	84,1	61,8	49,4	44,2	35,9	31,8	28,9	26,6	24,1	19,9	11,9	8,7	5,7	3,7	3,1	1,66
NP 24-12I	119	87,2	69,9	59,2	50,8	44,9	40,8	37,6	34,1	28,1	16,8	12,3	8,0	5,28	4,32	2,35
NP 38-12I	188	138	111	93,7	80,5	71,2	64,8	59,5	54,0	44,5	26,2	19,4	12,7	8,36	6,84	3,72
NP 65-12I	321	236	189	160	138	122	111	102	92,4	76,1	45,5	33,2	21,8	14,3	11,7	6,3

NP Konstantleistungsentnahme (Watt/Zelle) bei 1,75 V/Zelle Entladeschlußspannung bei 20°C
NP Constant Power-Discharge (Watt/cell) to 1.75 V/cell cut-off voltage at 20°C

Autonomie in Minuten / *Autonomy in minutes* — Autonomie in Stunden / *Autonomy in hours*

Typ – Type	5	10	15	20	25	30	35	40	45	1	2	3	5	8	10	20
NP 1-6	4,8	3,6	2,8	2,4	2,0	1,8	1,6	1,5	1,4	1,2	0,7	0,5	0,3	0,22	0,18	0,1
NP 1.2-6 / NP 1.2-12	5,6	4,3	3,4	2,8	2,5	2,2	2,0	1,8	1,6	1,4	0,8	0,6	0,4	0,26	0,22	0,12
NP 3-6	14,1	10,7	8,47	7,12	6,14	5,46	4,94	4,55	4,12	3,45	2,05	1,49	0,98	0,66	0,54	0,3
NP 4-6 / NP 4-12	18,8	14,2	11,3	9,5	8,2	7,3	6,6	6,1	5,5	4,6	2,7	2,0	1,3	0,87	0,71	0,41
NP 7-6 / NP 7-12	32,8	24,8	19,8	16,6	14,3	12,7	11,5	10,6	9,6	8,1	4,8	3,5	2,3	1,5	1,27	0,7
NP 10-6	46,9	35,5	28,2	23,7	20,5	18,2	16,5	15,2	13,7	11,5	6,8	5,0	3,3	2,2	1,8	1,0
NP 12-6 / NP12-12	56,3	42,6	33,9	28,5	24,6	21,8	19,8	18,2	16,5	13,8	8,2	6,0	3,9	2,6	2,18	1,22
NP 0.8-12	3,8	2,8	2,3	1,9	1,6	1,5	1,3	1,2	1,1	0,9	0,5	0,4	0,3	0,17	0,15	0,08
NP 2-12	9,3	7,1	5,7	4,7	4,1	3,7	3,3	3,1	2,7	2,3	1,4	0,9	0,63	0,43	0,36	0,2
NP 2.3-12	10,7	8,1	6,6	5,5	4,7	4,3	3,7	3,5	3,2	2,6	1,5	1,1	0,7	0,5	0,4	0,22
NP 3.2-12	15,0	11,3	10,9	7,6	6,5	5,8	5,3	4,8	4,4	3,7	2,2	1,6	1,0	0,74	0,58	0,32
NP 17-12I	79,8	60,4	48,0	40,3	34,8	31,0	28,0	25,8	23,3	19,6	11,6	8,6	5,6	3,7	3,1	1,66
NP 24-12I	113	85,2	67,7	56,9	49,2	43,7	39,6	36,4	32,9	27,6	16,4	12,0	7,8	5,2	4,31	2,35
NP 38-12I	178	135	107	90,1	77,8	69,2	62,6	57,6	52,2	43,7	25,4	18,8	12,4	8,3	6,9	3,72
NP 65-12I	305	231	183	154	133	118	107	98,6	89,2	74,8	44,3	32,2	21,2	14,2	11,8	6,3

NP Konstantleistungsentnahme (Watt/Zelle) bei 1,80 V/Zelle Entladeschlußspannung bei 20°C
NP Constant Power-Discharge (Watt/cell) to 1.80 V/cell cut-off voltage at 20°C

	Autonomie in Minuten *Autonomy in minutes*									Autonomie in Stunden *Autonomy in hours*						
Typ – Type	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**1**	**2**	**3**	**5**	**8**	**10**	**20**
NP 1-6	4,8	3,4	2,6	2,2	2,0	1,8	1,6	1,4	1,3	1,1	0,7	0,5	0,3	0,2	0,18	0,08
NP 1.2-6 / NP 1.2-12	5,4	4,1	3,1	2,7	2,4	2,1	1,9	1,7	1,6	1,3	0,8	0,6	0,4	0,26	0,21	0,12
NP 3-6	13,5	10,2	7,68	6,82	5,89	5,26	4,74	4,33	3,95	3,26	1,97	1,43	0,94	0,6	0,54	0,24
NP 4-6/NP 4-12	18	13,6	10,2	9,1	7,9	7,0	6,3	5,8	5,3	4,3	2,6	1,9	1,3	0,86	0,7	0,41
NP 7-6/NP 7-12	31,5	23,7	17,9	15,9	13,7	12,3	11,1	10,1	9,2	7,6	4,6	3,3	2,2	1,5	1,25	0,69
NP 10-6	44,6	33,9	25,6	22,7	19,6	17,5	15,8	14,4	13,2	10,9	6,6	4,8	3,1	2,1	1,8	1,0
NP 12-6 / NP 12-12	53,9	40,7	30,7	27,3	23,6	21,0	18,9	17,3	15,8	13,0	7,9	5,7	3,8	2,6	2,16	1,22
NP 0.8-12	3,6	2,7	2,0	1,8	1,6	1,4	1,3	1,2	1,1	0,9	0,5	0,4	0,3	0,17	0,14	0,08
NP 2-12	8,9	6,7	5,2	4,5	3,9	3,5	3,2	2,8	2,6	2,2	1,4	0,9	0,63	0,43	0,36	0,2
NP 2.3-12	10,3	7,8	5,9	5,3	4,5	3,9	3,6	3,3	3,1	2,5	1,5	1,1	0,7	0,5	0,4	0,23
NP 3.2-12	14,4	10,8	8,2	7,3	6,3	5,7	5,0	4,7	4,2	3,4	2,1	1,5	1,0	0,74	0,58	0,32
NP 17-12I	76,4	57,6	43,5	38,6	33,4	29,8	26,6	24,6	22,4	18,5	11,2	8,35	5,3	3,6	3,1	1,73
NP 24-12I	108	81,3	61,4	54,5	47,1	42,1	37,9	34,7	31,6	26,1	15,8	11,5	7,5	5,2	4,3	2,35
NP 38-12I	171	129	97,2	86,3	74,6	66,7	60,0	54,8	50,1	41,3	25,0	18,2	11,9	8,2	6,8	3,7
NP 65-12I	292	220	166	148	128	114	103	93,9	85,7	70,6	42,8	31,1	20,4	14,0	11,6	6,3

NP Konstantstromentnahme (Ampère) bei 1,60 V/Zelle Entladeschlußspannung (in Minuten/Stunden) bei 20°C
NP Constant Current Drain (Ampères) to 1.60 V/cell cut-off voltage (in minutes/hours) at 20°C

	Autonomie in Minuten *Autonomy in minutes*										Autonomie in Stunden *Autonomy in hours*						
Typ - Type	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**1**	**2**	**3**	**5**	**8**	**10**	**20**
NP1-6	3,20	2,30	1,70	1,40	1,20	1,04	0,90	0,84	0,77	0,72	0,63	0,37	0,27	0,18	0,15	0,11	0,05
NP1.2-6 / NP1.2-12	3,90	2,80	2,00	1,64	1,41	1,25	1,10	1,01	0,92	0,86	0,75	0,47	0,32	0,21	0,15	0,12	0,06
NP3-6	9,38	6,38	5,0	4,11	3,53	3,13	2,7	2,52	2,31	2,16	1,88	1,11	0,81	0,54	0,36	0,29	0,16
NP4-6 / NP4-12	12,5	9,30	6,90	5,60	4,71	4,20	3,70	3,36	3,00	2,88	2,60	1,48	1,08	0,72	0,48	0,39	0,21
NP7-6 / NP7-12	22,7	16,2	12,1	9,70	8,30	7,29	6,40	5,88	5,30	5,04	4,50	2,59	2,00	1,25	0,83	0,69	0,37
NP10-6	32,5	23,2	17,2	13,9	11,8	10,4	9,20	8,40	7,60	7,19	6,25	3,80	2,70	1,79	1,30	0,94	0,53
NP12-6 / NP12-12	39,0	27,8	20,7	16,6	14,1	12,5	11,0	10,1	9,10	8,63	7,50	4,50	3,30	2,14	1,43	1,17	0,70
NP0.8-12	2,60	1,90	1,40	1,10	0,96	0,83	0,74	0,68	0,62	0,58	0,52	0,31	0,22	0,16	0,10	0,08	0,04
NP2-12	6,50	4,60	3,40	2,74	2,35	2,08	1,70	1,68	1,50	1,44	1,26	0,77	0,55	0,36	0,25	0,20	0,11
NP2.3-12	7,40	4,89	3,90	3,15	2,71	2,40	2,10	1,93	1,80	1,66	1,44	0,85	0,62	0,49	0,27	0,23	0,12
NP3.2-12	10,4	7,40	5,50	4,38	3,77	3,33	2,90	2,69	2,50	2,30	2,00	1,19	0,90	0,58	0,41	0,31	0,17
NP17-12I	55,3	39,5	29,3	23,6	20,0	17,7	15,5	14,3	13,0	12,2	10,6	6,29	4,60	3,10	2,02	1,67	0,90
NP24-12I	75,0	51,1	40,0	32,9	28,2	25,0	22,0	20,2	18,3	17,3	15,2	8,89	6,49	4,30	2,86	2,40	1,26
NP38-12I	119	80,9	63,3	52,1	44,7	39,6	34,8	31,9	29,1	27,3	24,1	14,1	10,3	6,80	4,52	3,80	1,98
NP65-12I	203	138	108	89,0	76,5	67,7	59,5	54,6	49,2	46,8	40,6	24,1	17,6	11,6	7,74	6,50	3,42

NP Konstantstromentnahme (Ampère) bei 1,65 V/Zelle Entladeschlußspannung (in Minuten/Stunden) bei 20°C
NP Constant Current Drain (Ampères) to 1.65 V/cell cut-off voltage (in minutes/hours) at 20°C

	Autonomie in Minuten *Autonomy in minutes*									Autonomie in Stunden *Autonomy in hours*						
Typ - Type	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**1**	**2**	**3**	**5**	**8**	**10**	**20**
NP1-6	2,91	2,20	1,70	1,40	1,15	1,02	0,90	0,83	0,75	0,71	0,62	0,37	0,27	0,17	0,12	0,10	0,05
NP1.2-6 / NP1.2-12	3,60	2,60	2,00	1,60	1,40	1,22	1,10	1,00	0,90	0,85	0,74	0,44	0,32	0,21	0,14	0,12	0,06
NP3-6	8,72	6,09	4,80	4,00	3,45	3,06	2,70	2,48	2,25	2,12	1,85	1,09	0,80	0,52	0,35	0,29	0,15
NP4-6 / NP4-12	12,2	8,70	6,60	5,50	4,70	4,10	3,70	3,31	3,00	2,83	2,50	1,50	1,10	0,70	0,48	0,39	0,21
NP7-6 / NP7-12	21,2	15,2	11,6	9,60	8,10	7,14	6,40	5,79	5,20	4,95	4,40	2,56	1,86	1,22	0,82	0,68	0,36
NP10-6	30,5	21,8	16,7	13,7	11,6	10,2	9,10	8,26	7,50	7,07	6,15	3,65	2,65	1,80	1,17	0,97	0,52
NP12-6 / NP12-12	36,5	26,0	20,0	16,4	13,9	12,2	10,9	9,92	9,00	8,48	7,39	4,40	3,18	2,10	1,40	1,20	0,66
NP0.8-12	2,50	1,80	1,40	1,10	0,94	0,82	0,74	0,68	0,60	0,57	0,49	0,31	0,21	0,16	0,94	0,08	0,04
NP2-12	6,10	4,30	3,30	2,67	2,30	2,04	1,70	1,65	1,50	1,41	1,30	0,76	0,55	0,35	0,25	0,19	0,11
NP2.3-12	7,00	5,00	3,80	3,20	2,70	2,35	2,10	1,90	1,80	1,63	1,42	0,90	0,61	0,40	0,27	0,22	0,12
NP3.2-12	9,80	6,90	5,30	4,40	3,68	3,27	2,90	2,65	2,40	2,26	1,97	1,20	0,89	0,56	0,37	0,31	0,17
NP17-12I	52,6	37,1	27,4	23,3	19,7	17,3	15,4	14,1	12,8	12,0	10,5	6,20	4,60	2,97	2,10	1,65	0,89
NP24-12I	70,6	49,0	38,4	32,0	27,8	24,5	21,8	19,8	18,1	17,0	14,8	8,76	6,37	4,20	2,81	2,40	1,24
NP38-12I	112	77,5	60,8	50,7	43,7	38,8	34,4	31,4	28,5	26,9	23,4	13,9	10,1	6,64	4,45	3,80	1,96
NP65-12I	191	133	104	86,7	75,3	66,3	58,9	53,7	48,6	45,9	40,1	23,7	17,2	11,4	7,61	6,50	3,35

NP Konstantstromentnahme (Ampère) bei 1,70 V/Zelle Entladeschlußspannung (in Minuten/Stunden) bei 20°C
NP Constant Current Drain (Ampères) to 1.70 V/cell cut-off voltage (in minutes/hours) at 20°C

	Autonomie in Minuten *Autonomy in minutes*									Autonomie in Stunden *Autonomy in hours*						
Typ - Type	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**1**	**2**	**3**	**5**	**8**	**10**	**20**
NP1-6	2,80	1,94	1,54	1,40	1,12	0,99	0,90	0,81	0,74	0,69	0,61	0,36	0,26	0,17	0,11	0,10	0,05
NP1.2-6 / NP1.2-12	3,29	2,40	1,90	1,56	1,35	1,19	1,10	0,97	0,88	0,83	0,73	0,43	0,31	0,21	0,14	0,11	0,06
NP3-6	8,22	5,83	4,62	3,90	3,37	2,97	2,70	2,43	2,22	2,08	1,82	1,08	0,78	0,51	0,34	0,29	0,15
NP4-6 / NP4-12	11,2	7,77	6,30	5,40	4,60	3,96	3,60	3,30	2,90	2,78	2,42	1,50	1,04	0,68	0,46	0,38	0,20
NP7-6 / NP7-12	19,5	13,6	10,8	9,40	7,87	6,93	6,30	5,67	5,10	4,86	4,30	2,60	1,82	1,20	0,81	0,67	0,35
NP10-6	28,0	20,0	15,4	13,5	11,2	9,90	9,00	8,20	7,30	6,94	6,10	3,60	2,60	1,71	1,15	0,95	0,51
NP12-6 / NP12-12	33,5	24,0	19,0	16,1	13,6	11,9	10,8	9,80	8,80	8,33	7,30	4,32	3,12	2,05	1,38	1,14	0,61
NP0.8-12	2,30	1,55	1,30	1,10	0,90	0,79	0,74	0,68	0,57	0,56	0,49	0,29	0,21	0,15	0,09	0,08	0,04
NP2-12	5,60	3,88	3,20	2,60	2,25	1,98	1,70	1,62	1,50	1,39	1,21	0,75	0,54	0,34	0,23	0,19	0,10
NP2.3-12	6,50	4,60	3,60	3,10	2,58	2,30	2,10	1,86	1,58	1,60	1,39	0,90	0,60	0,39	0,26	0,22	0,12
NP3.2-12	8,76	6,40	4,92	4,30	3,60	3,17	2,80	2,59	2,30	2,22	1,94	1,20	0,87	0,55	0,39	0,31	0,16
NP17-12I	47,6	34,0	26,9	22,9	19,2	16,8	15,3	13,9	12,5	11,8	10,3	6,12	4,50	2,91	1,95	1,62	0,86
NP24-12I	66,7	46,6	36,9	31,2	27,3	24,0	21,6	19,4	17,6	16,7	14,6	8,63	6,24	4,10	2,76	2,39	1,21
NP38-12I	106	73,8	58,5	49,4	43,2	38,0	34,1	30,8	27,9	26,4	23,0	13,7	9,90	6,50	4,37	3,78	1,92
NP65-12I	181	126	100	84,4	73,9	65,0	58,2	52,6	47,9	45,1	39,4	23,4	16,9	11,1	7,48	6,47	3,28

NP Konstantstromentnahme (Ampère) bei 1,75 V/Zelle Entladeschlußspannung (in Minuten/Stunden) bei 20°C
NP Constant Current Drain (Ampères) to 1.75 V/cell cut-off voltage (in minutes/hours) at 20°C

	Autonomie in Minuten *Autonomy in minutes*									Autonomie in Stunden *Autonomy in hours*						
Typ - Type	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**1**	**2**	**3**	**5**	**8**	**10**	**20**
NP1-6	2,58	2,00	1,47	1,24	1,07	0,95	0,85	0,78	0,73	0,66	0,58	0,36	0,26	0,16	0,11	0,09	0,05
NP1.2-6 / NP1.2-12	3,09	2,40	1,90	1,48	1,28	1,20	1,10	0,95	0,83	0,80	0,70	0,40	0,30	0,20	0,13	0,11	0,06
NP3-6	7,73	5,56	4,41	3,70	3,21	2,86	2,55	2,34	2,19	1,99	1,74	1,01	0,75	0,49	0,33	0,28	0,15
NP4-6	10,4	7,80	6,20	5,20	4,40	3,90	3,50	3,20	2,80	2,65	2,40	1,40	1,00	0,66	0,46	0,37	0,20
NP7-6 / NP7-12	18,2	13,6	11,0	9,00	7,70	6,67	6,10	5,60	5,00	4,64	4,20	2,50	1,80	1,15	0,78	0,65	0,35
NP10-6	25,8	19,5	15,5	12,9	11,1	9,70	8,80	7,81	7,10	6,62	6,00	3,50	2,60	1,65	1,11	0,93	0,50
NP12-6 / NP12-12	31,3	23,4	18,6	15,5	13,3	11,6	10,5	9,60	8,60	7,95	7,20	4,02	3,11	1,98	1,33	1,11	0,60
NP0.8-12	2,06	1,48	1,30	0,99	0,86	0,76	0,71	0,63	0,57	0,53	0,47	0,27	0,20	0,15	0,09	0,08	0,04
NP2-12	5,16	3,90	3,20	2,47	2,30	2,00	1,70	1,56	1,40	1,33	1,16	0,74	0,53	0,33	0,22	0,19	0,11
NP2.3-12	5,92	4,50	3,60	3,00	2,60	2,30	2,00	1,90	1,60	1,52	1,40	0,77	0,58	0,38	0,26	0,21	0,12
NP2.8-12	7,26	5,50	4,30	3,70	3,00	2,67	2,50	2,30	2,00	1,85	1,70	0,97	0,70	0,46	0,33	0,26	0,14
NP3.2-12	8,40	6,30	4,90	4,20	3,60	3,10	2,80	2,60	2,30	2,12	2,00	1,10	0,86	0,53	0,38	0,30	0,16
NP17-12I	44,3	33,1	26,3	21,9	18,8	16,4	14,8	13,6	12,1	11,3	9,86	6,00	4,40	2,80	1,88	1,57	0,87
NP24-12I	61,9	44,4	35,3	29,6	26,7	22,9	21,1	18,8	17,1	15,9	14,1	8,14	6,00	3,95	2,66	2,38	1,20
NP38-12I	97,9	70,4	55,9	46,9	42,1	36,2	33,3	29,7	27,2	25,2	22,0	12,9	9,50	6,26	4,21	3,76	1,90
NP65-12I	168	120	95,6	80,3	71,9	61,9	57,1	50,8	46,5	43,1	38,2	21,8	16,3	10,7	7,20	6,44	3,25

NP Konstantstromentnahme (Ampère) bei 1,80 V/Zelle Entladeschlußspannung (in Minuten/Stunden) bei 20°C
NP Constant Current Drain (Ampères) to 1.80 V/cell cut-off voltage (in minutes/hours) at 20°C

	Autonomie in Minuten *Autonomy in minutes*									Autonomie in Stunden *Autonomy in hours*						
Typ - Type	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**1**	**2**	**3**	**5**	**8**	**10**	**20**
NP1-6	2,60	1,77	1,41	1,18	1,10	1,00	0,85	0,75	0,68	0,63	0,56	0,36	0,26	0,16	0,11	0,09	0,05
NP1.2-6 / NP1.2-12	2,93	2,20	1,69	1,50	1,30	1,20	1,00	0,90	0,84	0,76	0,68	0,40	0,29	0,19	0,13	0,11	0,06
NP3-6	7,32	5,31	4,23	3,53	3,06	2,73	2,55	2,24	2,04	1,90	1,67	1,09	0,79	0,52	0,35	0,29	0,15
NP4-6 / NP4-12	9,90	7,40	5,63	5,00	4,30	3,80	3,40	2,99	2,80	2,53	2,22	1,40	0,96	0,70	0,44	0,35	0,19
NP7-6 / NP7-12	17,4	13,0	9,86	8,70	7,40	6,70	6,14	5,40	4,80	4,43	3,89	2,39	1,69	1,11	0,76	0,62	0,35
NP10-6	24,8	18,6	14,1	12,4	10,7	9,50	8,50	7,71	6,90	6,33	5,56	3,33	2,49	1,59	1,07	0,92	0,48
NP12-6 / NP12-12	29,8	22,3	16,9	14,8	12,8	11,4	10,2	9,20	8,30	7,60	6,80	4,10	2,89	1,91	1,28	1,10	0,57
NP0.8-12	1,95	1,46	1,13	0,94	0,86	0,80	0,70	0,60	0,57	0,51	0,47	0,27	0,19	0,15	0,09	0,07	0,04
NP2-12	4,88	3,69	2,82	2,35	2,10	1,90	1,70	1,49	1,40	1,27	1,20	0,74	0,48	0,32	0,21	0,18	0,10
NP2.3-12	5,61	4,30	3,29	2,71	2,35	2,20	2,00	1,80	1,60	1,46	1,28	0,77	0,55	0,37	0,25	0,20	0,11
NP3.2-12	7,85	5,90	4,51	3,90	3,40	3,10	2,70	2,50	2,20	2,03	1,78	1,10	0,77	0,51	0,37	0,29	0,15
NP17-12I	42,2	31,6	23,9	21,1	18,1	16,1	14,5	13,1	11,8	10,8	9,60	5,80	4,30	2,70	1,82	1,50	0,85
NP24-12I	58,5	42,5	33,8	28,2	25,6	21,8	20,5	17,9	16,6	15,2	13,3	8,00	5,78	3,82	2,57	2,36	1,14
NP38-12I	92,7	67,9	53,5	44,7	40,5	34,6	32,4	28,4	26,4	24,1	21,1	12,7	9,40	6,03	4,06	3,36	1,81
NP65-12I	159	116	91,6	76,5	69,4	59,1	54,5	48,5	45,1	41,1	36,1	21,7	15,7	10,3	6,95	6,40	3,26

1.0 Lagerung – *Storage*

Falls die Batterien nicht sofort installiert und in Betrieb genommen werden sollen, ist es empfehlenswert, die Batterien in den Kartons zu belassen und an einem kühlen, sauberen und trockenen Ort zu lagern. Bei einer Lagerung über 6-9 Monate ab Produktionsdatum können die Batterien durch eine Ergänzungsladung auf ihre volle Kapazität aufgeladen werden.

If the batteries are not to be installed immediately, keep them boxed and stored in a cool, clean and dry place. If the batteries are to be stored for six months or more from date of production, a supplementary charge can be carried out to restore their full capacity.

2.0 Sichtkontrolle bei Entnahme – *Unpacking and Inspection*

Vorsicht: Batterien sind elektrochemisch permanent aktiv und spannungsführend – verbinden Sie daher nicht die Batteriepole direkt oder überbrücken Sie diese nie ohne Lastwiderstand.
Überprüfen Sie jede Batterielieferung in Bezug auf Transportschäden. Stellen Sie sicher, daß die Lieferung alle Gegenstände umfaßt, die auf dem Lieferschein oder auf der Rechnung aufgeführt sind, wie z. B. Verbinder, Abdeckkappen etc. Entnehmen Sie jede Batterie vorsichtig und achten Sie darauf, daß die Batteriepole nicht beschädigt werden. Prüfen Sie jede Batterie auf mechanische Beschädigung wie Risse oder Deformationen des Batteriegehäuses oder der Batteriepole. Messen Sie die offene Klemmenspannung, die pro Zelle über 2,1V liegen sollte.

Danger: Batteries are electrochemically live at all times. Do not short circuit the battery terminals.
Inspect the battery consignment for signs of transport damage. Ensure the consignment has all items listed on the delivery note or invoice, i.e. batteries, cables, shrouds etc.
While unpacking each battery, take care not to drop anything on the terminals. Inspect each battery for physical damage such as cracks or distortion of the case and terminals.
Measure the battery open circuit terminal voltage which should be > 2.1 Volt/cell o.c.v.

3.0 Ergänzungsladung – *Supplementary charge*

Um eine optimale Gebrauchsdauer zu erzielen, sollte vor Inbetriebnahme eine Ergänzungsladung bei einer offenen Klemmenspannung kleiner als 2,1 V/Zelle erfolgen.

To ensure maximum service life, a supplementary charge should be carried out if the open circuit voltage is less than 2.1 Volts per cell.

Führen Sie die Ergänzungsladung gemäß folgender Tabelle durch:
A supplementary charge should be applied in accordance with figures shown in the table below:

Ergänzungsladung NP – *Supplementary charge for the NP Battery range*

Lagerdauer in Bezug auf Produktionsdatum *Storage Period*	Ladespannung/Zelle *Charge Voltage per Cell*	Ladezeit *Charge Time*
weniger als 1 Jahr *less than 1 year*	2,275 V/Zelle *2,275V/cell*	länger als 72 Stunden *more than 72 hours*
12 Monate und länger *1 year and more*	2,35 V/Zelle *2,35 V/cell*	mind. 48 Std; max. 144 Std. *48 to 144 hours*

Nach erfolgter Ladung prüfen Sie bitte die offene Klemmenspannung, die nach dem Ende des Ladevorgangs über 2,15 Volt/Zelle innerhalb 24 Stunden liegen sollte. Falls dieser Wert nicht erreicht wird, sollte die Batterie einmal entladen und wieder aufgeladen werden.

After completion of charging, please check that the battery open circuit voltage is above 2,15 Volts / cell within 24 hours from the end of charge. If not, one discharge/charge cycle will improve o.c.v. performance.

4.0 Check-Liste vor der Installation – *Pre-installation Check list*

Vorsicht: Batterien dürfen nicht in abgeschlossenen Behältnissen betrieben werden.
Sorgen Sie für eine ausreichende Belüftung gemäß EN50272-2:2001.

Zu beachten: Eine permanente Batterietemperatur über 20°C reduziert die Gebrauchsdauer (siehe dazu Tabelle Abschnitt 5.1.)

Danger: *Batteries must not be installed in a sealed container.*
Please check for sufficient ventilation according to EN 50272-2:2001.
A battery operational temperature of more than 20°C reduces the service life (see table in section 5.1.).

4.1. Installation – *Installation*

Verwenden Sie einen Drehmomentschlüssel zur Montage der Blockverbinder. Stellen Sie das Drehmoment gemäß Tabelle 4.3 ein. Arbeiten Sie nur mit isoliertem Werkzeug! Beim Hantieren mit Batterien empfiehlt sich das Ablegen jeglichen Schmucks, Uhren und Ringen. Bei der Installation muss ein Luftspalt von 5-10 mm zwischen den einzelnen Blöcken vorgesehen werden. Achten Sie auf den Sicherheitsabstand zwischen Batterien und funkenbildenden Betriebsmitteln. Das Batteriegehäuse besteht aus "ABS"-Kunststoff und darf nicht mit organischen Lösungsmitteln oder Klebstoffen in Berührung kommen.

Please use a torque wrench to fasten the connectors onto the battery terminals. The torque should be adjusted according to the values shown in table 4.3. Please use only insulated tools! Remove all jewellery, watches and rings. If rings cannot be removed, insulate them with 3 layers of insulating tape. For sufficient installation, a distance of 5-10 mm between the battery blocks is necessary. Do not install the batteries close to any source of ignition, such as electrical switches or any components that may produce sparks.
The battery case is made from ABS resin, do not place it in an atmosphere with organic solvents or adhesive material.

4.2 Verbinden von Batterien - *Battery Connection*

Beim Verbinden von Batterien zu Batteriesträngen gehen Sie bitte methodisch vor. Verbinden Sie den negativen Anschlusspol einer Batterie mit dem positiven Anschlusspol der nächsten Batterie, und so weiter. Am Ende verbinden Sie die positive und negative Endableitung mit der Last oder dem Gleichrichter. Zur Parallelschaltung mehrerer Batteriestränge führen Sie alle positiven Endableiter auf den Pluspol und alle negativen Endableiter auf den Minuspol einer Sammelschiene oder Klemmleiste. Isolieren Sie alle Batteriepole.

When connecting batteries in a series string, always work methodically. Connect the negative terminal of one battery to the positive terminal of the next battery, and so on. Finally connect the positive and negative take-off loads to the system load or rectifier. For parallel connection of several battery strings, connect all positive take-offs to the positive terminal and all negative take-offs to the negative terminal of a bus bar or terminal block. Ensure all battery terminals are insulated.

4.3. Drehmomente der Polschrauben – *Fastening terminal bolts*

Die folgende Tabelle zeigt die optimalen Drehmomente für die Batteriepole.
The following table shows the optimal torque settings for terminal bolts.

Batterie *Battery*	Gewindedurchmesser *Bolt Diameter*	Drehmoment (Nm) *Fastening Torque (Nm)*
NP 17 -12I	M 5	2-3 Nm
NP 24 -12I	M 5	2-3 Nm
NP 38 -12I	M 5	2-3 Nm
NP 65 -12I	M 6	4-5,5 Nm

Bei starker Überschreitung der o.g. Drehmomente können die Anschlusspole der Batterien zerstört werden.
If the above mentioned torques are exceeded seriously, the battery terminals may be damaged.

5.0 Aufladen und Inbetriebnahme – *Charging and Commissioning*

Nach dem Verschalten der Batterien kann die Ladespannung zugeschaltet werden. Die Schwebeladespannung beträgt 2,275 Volt/Zelle +/-1% bei 20°C. Nach 12-24 Stunden steht die Batteriekapazität zur Verfügung.
After connecting the battery system, the charge voltage can be applied. The float charge voltage is 2,275 V/cell +/-1% at 20°C. The nominal capacity is achieved after 12-24 hours charging.

5.1. Schwebeladespannung, Temperatur und Gebrauchsdauer – *Float charge voltage, Temperature and Design Life*

Bei von 20°C abweichenden Batterietemperaturen muss mit -3mV/Zelle/°C kompensiert werden (siehe nachfolgende Tabelle). Vorsicht: Eine erhöhte Batterietemperatur wirkt sich negativ auf die Gebrauchsdauer unter Schwebeladespannung aus.

If the battery temperature is not 20°C, the charging voltage must be compensated by -3mV/cell/°C (see the table below). ***Caution:*** *High operational temperature will have a severely detrimental effect on the battery life.*

Batterietemperatur [°C] *Operational Temperature [°C]*	Schwebeladespannung [V/Zelle] *Float Charge Voltage [V/cell]*	Gebrauchsdauer (unverb.) [Jahre] *Expected Battery Life (noncommittal) [years]*
0	2,335	5
5	2,320	5
10	2,305	5
15	2,290	5
20	2,275	5
25	2,260	3,5
30	2,245	2,5
35	2,230	1,75
40	2,215	1,25
45	2,200	10 Monate / *months*
50	2,185	7,5 Monate / *months*

5.2. Entladeschlußspannung – *Setting a Cut-Off Voltage*

Bei einer Entladung fällt die Batteriespannung unter ihren Nennwert von 2 Volt pro Zelle. Um einer zu tiefen Entladung und den daraus resultierenden Schäden entgegen zu wirken, darf die Entladeschlußspannung 1,6 V/Zelle nicht unterschreiten.

During the discharge, the battery voltage will fall below the nominal value of 2 Volts per cell. In order to prevent over-discharging and possible damage to the battery, the cut-off voltage must not be below 1.6 Volts per cell.

5.3. AC Ripple Current – effektive Welligkeit des Ladegleichstromes – *AC Ripple Current (the AC component on the DC charge current)*

Um eine optimale Gebrauchsdauer der Batterie zu erzielen, sollte die gemessene Welligkeit (R.M.S.) beim Gleichstrom möglichst gegen „0“ streben und auf jeden Fall kleiner als 0,1 C für Kapazitäten bis zu 17 Ah und kleiner als 0,05 C(A) bei Kapazitäten ab 24 Ah sein.

To obtain maximum service life of the battery, the value of measured AC ripple at R.M.S. on the DC charge current should be Zero but by no means more than 0,1 C for battery capacities up to 17 Ah and not more than 0,05 C(A) for capacities more than 24 Ah.

6.0 Inspektion und Wartung – *Inspection and Maintenance*

Um Problemen während des Betriebes vorzubeugen, wird empfohlen, die Batterien alle 6 Monate mit einem Kapazitätstest zu entladen und wieder voll aufzuladen. Während eines einjährigen Wartungsintervalls sollten die Blockspannungen während der Ladung und der Spannungsverlauf während der Entladung registriert werden. Den Höchstwert der Batterietemperatur zwischen den Inspektionen sollte ein Temperaturstreifen festhalten. Im Rahmen einer verlängerten Garantie sind diese und andere Werte zur Registrierung und Begutachtung YUASA Battery (EUROPE) GmbH Düsseldorf vorzulegen. Wartungsformblätter sind auf Wunsch erhältlich.

To prevent battery problems, the inspection and maintenance procedures outlined need to be implemented. During annual service inspections, take and log the voltage readings per battery block and make them accessible to YUASA Battery (EUROPE) GmbH. *This will act as a historical battery system record which will assist in the early detection of possible system problems before they have a chance to develop (Voltage log sheet on request available from* YUASA Battery (EUROPE) GmbH*).*

7.0 Kundenservice – *Customer Service*

In Zweifelsfällen und bei sonstigen technischen Fragen wenden Sie sich bitte an den technischen Kundendienst Ihres Distributors/Händlers oder an YUASA Battery (EUROPE) GmbH: Tel.: +49 / (0) 211/417 90-16 · Fax: +49 / (0) 211/417 90-11

If you have any queries concerning your battery system please contact the technical department of your local distributor/ dealer or YUASA Battery (EUROPE) GmbH*: Tel. : +49 / (0) 211/ 417 90-16 · Fax: +49 / (0) 211/ 417 90-11*

Zu beachten:

1. Die Konstant-Strom- bzw. Konstant-Leistung-Entladedaten der NP Baureihe beziehen sich auf eine Batterietemperatur von 20°C. Diese Werte sind als nominell und damit garantiert zu betrachten. Typische Werte übertreffen regelmäßig die nominellen Werte unter gleichen Bedingungen bei allen Batterietypen und können bei Bedarf gesondert erfragt werden.
2. Die geschätzte Betriebslebensdauer der NP Baureihe von 3 – 5 Jahren kann unter den empfohlenen Betriebsbedingungen erzielt werden, wenn dauerhaft eine Batterietemperatur von 20°C vorherrscht, die Batterie mit einer Schwebeladespannung von 2,275 V/Z ± 1% geladen wird und eine den Konstantladestrom überlagernde effektive Welligkeit den Wert von 0,05 C(A) nicht überschreitet.
3. Zur Vermeidung eines zu stark ansteigenden Ladestromes bei thermisch bedingter Absenkung des Innenwiderstandes der Batterie (thermal runaway), der sich ab 30°C zerstörerisch auf die Batterie auswirken kann, wird empfohlen, bei Temperaturen über 20°C die Schwebeladespannung um -3 mV/Zelle/°C abzusenken.
4. In Folge eines ansteigenden Innenwiderstandes der Batterie bei Temperaturen unter 20°C wird empfohlen, die Schwebeladespannung um + 3 mV/Zelle/°C zu erhöhen.
5. Bei Temperaturen höher als 20°C vermindert sich die Lebensdauer der Batterie trotz temperaturgestützter Spannungskompensation der Schwebeladespannung.
6. Um die optimale Betriebslebensdauer der NP-Baureihe zu erreichen, sind unsere gesondert erstellten Installations-, Behandlungs- und Inbetriebsetzungsvorschriften einzuhalten.

To be noted:

1. *Constant current and constant power discharge data of the NP series are taken at 20°C battery temperature. These are nominal values and thereby guaranteed. Typical values regularly exceed the nominal guaranteed ones for all battery types under the same test conditions and can be readily made available on special request.*
2. *The estimated service life of the NP series is 3 – 5 years and can be achieved under recommended service conditions provided that the battery is permanently kept on float-charge of 2,275 V/cell ± 1% at 20°C and that the ripple current does not exceed 0,05 C(A).*
3. *The maximum service life can only be obtained by float-charging at the correct voltage, which depends on the temperature. Temperature compensation is required to avoid thermal runaway (at temperatures above 30°C), overcharge at high temperature and undercharge at low temperature.*
   The recommended temperature compensation factor is -3 mV/cell/°C with reference to a standard temperature of 20°C.
4. *Owing to a rising internal resistance of the batteries at temperatures below 20°C, it is recommended to increase the float-charge voltage by +3 mV/cell/°C.*
5. *At temperatures above 20°C service life of the battery will be diminished even if temperature compensated float-charging is applied.*
6. *In order to achieve the optimal service life of the NP series, please respect our installation, operation and maintenance instructions.*

YUASA

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