The battery as power source

There are different kinds of rechargeable batteries. The most common type is the lead acid battery. A less familiar one is the nickel-cadmium (NiCad) battery, which can still often be found in old emergency power systems. Due to the high charge voltage required by a NiCad battery, and the fact that they are very environmentally unfriendly, these batteries are not suitable for use onboard a vessel or car/truck.

Principle of the lead acid battery

A battery is a device that stores electric power in the form of chemical energy. When necessary, the energy is again released as electric power for DC consumers such as lighting and starter motors. A battery consists of several galvanic cells with a voltage of 2 Volt each. For a 12 Volt battery, six cells are linked in series and fitted inside a single casing. To achieve 24 Volt, two 12 Volt batteries are linked in series. Each cell has positive oxidised lead plates and negative lead metal plates, and has an electrolyte consisting of water and sulphuric acid. During discharging, the lead oxide on the lead plates is converted into lead. The acid content decreases because sulphuric acid is required for this process.

To recharge the battery, an external power source - such as a battery charger, alternator or solar panel - with a voltage of around 2.4 V per cell must be connected. The lead sulphate will then be converted back into lead and lead oxide, and the sulphuric acid content will rise. There are limits set for the charge voltage to prevent the release of an excessive amount of hydrogen. A charge voltage of more than 2.4 V per cell, for instance, releases a lot of hydrogen gas, which can form a highly explosive mixture with the oxygen in the air.

The upper limit on charge voltage for a 12 V battery is 14.4 V, and the corresponding value for a 24 V battery is 28.8 V at 20 °C. The relationship between how full a battery is and the specific gravity of the water/sulphuric acid mixture is as follows:

percentage charged	battery voltage	specific gravity	percentage discharged
0%	11.64 V	1.100	± 100%
20%	11.88 V	1.140	± 80%
40%	12.09 V	1.175	± 60%
60%	12.30 V	1.210	± 40%
80%	12.51 V	1.245	± 20%
100%	12.72 V	1.280	0%

Different types of battery - in terms of the thickness and number of plates per cell - correspond to different applications. The maximum current that can be delivered is determined by the total plate surface. The number of times that a battery can be discharged and recharged - the number of cycles - depends on the thickness of the plates. A battery can feature either many thin plates or a few thick ones.

The starter battery

A starter battery has many thin plates per cell, leading to a large total plate surface. This type of battery is, therefore, suitable for delivering a high level of current over a short period of time.
The number of times that a starter battery can be heavily discharged is limited to around 50-80. But as starting the engine uses only a small part of the energy stored (around 0.01%), the battery lasts for many years. This type of battery is generally unsuitable for cyclic use.

The Lithium Ion battery

Until recently Lithium Ion batteries were mainly available as chargeable batteries with a small capacity, which made them popular for use in mobile phones and laptops. Mastervolt offers Lithium Ion batteries with large capacities. Our Lithium Ion batteries have a high energy density and are perfect for cyclic applications. Compared to traditional lead acid batteries, Lithium Ion batteries offer savings of up to 70% in volume and weight, while the number of charging cycles is three times higher, compared to semi-traction lead acid batteries.

An added benefit is that Lithium Ion batteries can supply a constant capacity, regardless of the connected load. The available capacity of a lead acid battery is reduced in case of higher discharge currents. Lithium Ion batteries can be discharged to 80% without affecting their lifespan, whereas lead acid batteries are more affected by deep discharge.

Lasts longer

Lithium Ion batteries also offer major benefits compared to nickel-cadmium batteries, such as a much larger power density and a longer lifespan.

And because lithium is the lightest metal, Lithium Ion batteries are also more lightweight. They can also be charged at any time, while nickel-cadmium batteries require complete discharge for an optimal performance and to prevent memory effect. Furthermore, Lithium Ion batteries can be charged with a very high current, up to 100% of the capacity, resulting in a very short charging time and no memory effect.

Battery Management System

Mastervolt Lithium Ion batteries are equipped with a Battery Management System that automatically compensates for the imbalance between the cells and increases the lifespan.

The traction battery

(Mastervolt does not have this type of batteries in its portfolio)

This type of battery has even fewer, but very thick, flat or cylindrical plates. It can therefore be discharged many times and fairly completely (1000-1500 full cycles). This is why wet traction batteries are often used in forklifts and small electrical equipment such as industrial-grade cleaning machines.

But wet traction batteries require a special charge method. Because these batteries are mostly tall, they are sensitive to the accumulation of sulphuric acid at the bottom of the battery container. This phenomenon is called stratification and occurs because sulphuric acid is denser than water. Acid content increases in the lower part of the battery, locally intensifying plate corrosion, and decreases in the upper part, reducing capacity.

The battery is discharged unevenly, significantly reducing its lifespan. In order to spread out the acid evenly again, the battery has to be purposefully overloaded using excessive voltage. This generates a large amount of hydrogen gas, which will form a dangerous mixture with oxygen in the air. The voltage required to recharge these batteries is around 2.7 Volt per cell, or 16.2 Volt for a 12 V system and 32.4 Volt for a 24 V system. These high levels of voltage are extremely dangerous for the connected equipment and the large amount of gas generated makes these batteries unsuitable for use in vessels and vehicles, except for propulsion.

The semi-traction battery

A semi-traction battery has fewer but thicker plates in each cell. These batteries supply a relatively lower starter current, but can be discharged more often and to a greater extent (200 to 600 full cycles). This kind of battery is highly appropriate for the combined function of starter and service battery.

Frequently asked questions about batteries

How long will it take before my battery is discharged?

This depends on its capacity and the amount of power consumed by the connected equipment. As a rule, the faster a battery is discharged, the less power it supplies. This also works the other way around: The longer it takes before a battery discharges, the more energy you can get from it.
A 100 Ah lead-acid battery supplies a current of 5 amps for 20 hours, during which time the voltage does not drop below 10.5 Volt. This amounts to 100 Ah. If a load of 100 amps is connected to the same battery, the battery will be able to power it for only 45 minutes. After this time the battery voltage will fall to 10.5 Volt and the battery will be empty, having supplied no more than 75 Ah. In contradiction to the lead-acid batteries, the capacity of Lithium Ion batteries will not be effected by the load connected. A Li-ion battery will always supply 100% capacity, independent of the connected load.

How long will my battery last?

The lifespan of a battery is related to how often and to what extent it is discharged. Proper charging with the right charger is also crucial. At a normal use for holidays and weekends, a lifespan of between five and seven years is quite common for gel and AGM batteries. When batteries are frequently discharged you will need to adjust the capacity. There is also an option to use 2 Volt cells. A lifespan of 15 years is not exceptional for this type of battery as long as they have the right capacity and are properly charged. Lithium Ion batteries are top of the bill. You can discharge and recharge them super fast and they last up to three times as many cycles than other types of batteries.

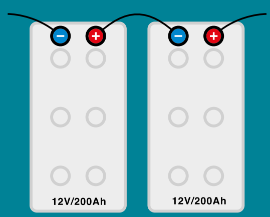
What is series connection and parallel connection?

A series connection is used to increase voltage, while keeping capacity at the same level. Two serially connected 12 V/120 Ah batteries make a combined battery set of 24 V/120 Ah. In a series connection, the positive pole of one battery is connected to the negative pole of the other, with the poles that remain at the ends being connected to the system. Batteries with different capacities should never be linked in series.

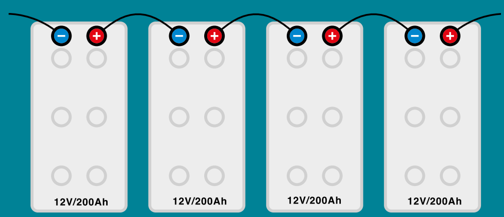
Examples

The examples below apply to the use of normal 12 V batteries. Mastervolt also supplies 2 V, 6 V and 24 V batteries; the principle of series and parallel connecting remains the same.

Series connection



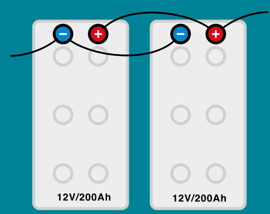
Series connection 24 V/200 Ah.



Series connection 48 V/200 Ah.

Parallel connection

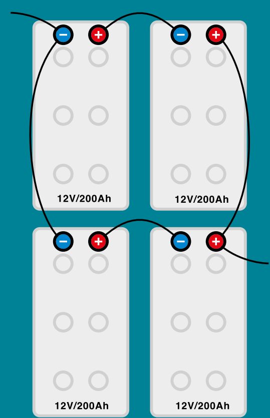
Parallel connection is used when you need to increase your capacity. The positive leads are connected together, as are the negative leads. The cabling from the battery to the system should be: Positive from battery 1 and negative from battery 2 (or the last in the parallel connection).



Parallel connection 12 V/400 Ah.

Series/parallel connection

If you need a 24 V battery set with a higher capacity, you can combine series and parallel connections. The cables from the battery to the system must be crossed: Positive from battery 1 and negative from battery 2 (or the last in the parallel connection).



Series/parallel connection 24 V/400 Ah.

Make sure there is sufficient space between the batteries when installing multiple batteries: There should be a 'finger' of space between them to allow the heat to be diverted.

What *NOT* to do with batteries, especially gel and AGM

- Incorrect charge voltage. Too low a voltage means that the battery cannot charge to 100% - the sulphate then hardens on the plates and the battery loses its capacity. Excessive voltage causes the batteries to generate gas, leading to water loss and drying out.
- Excessive discharging. Discharging a battery further than its capacity shortens its lifespan.
- Too large ripple on the charge voltage. Cheap and old-fashioned chargers often have a significant voltage ripple (voltage variation) in the output voltage.
- The use of an alternator without 3-step regulator, a high ambient temperature or charging without temperature compensation.

Can I leave the batteries onboard during winter?

This is fine for all batteries as the lower temperature will actually prolong their lifespan. Remember to charge the batteries completely and to ensure that no consumers are left on. Voltmeters, timers and car radio memory are some of the stealthy consumers to look out for in this respect. Wet batteries have to be regularly topped up and charged to avoid freezing. It is advisable to connect the power once every two to three weeks so the batteries can be fully recharged. If you do not have access to power during the winter we advise you to fully charge the batteries before the winter and then disconnect the battery poles so small users cannot discharge your battery. We also advise charging your battery every two months.

How should I maintain gel, AGM and Lithium Ion batteries?

Gel, AGM and Lithium Ion batteries do not need maintenance, which means they can be installed anywhere. However, we recommend checking all the connections once a year to make sure that they are properly attached, and to clean the top surfaces with a slightly moist cloth. The batteries also need to be completely charged every time for a maximum lifespan.

What are maintenance-free batteries?

Various types of batteries are used, each with its own specific characteristics.
Here is a summary:

The gel battery

With wet lead acid batteries, that use a liquid electrolyte of water and sulphuric acid, the water is seperated into hydrogen and oxygen during charging, mostly at the end of the charging cycle. These gases subsequently escape through the filler cap. This means water is used and distilled (battery) water needs to be added.The electrolyte in a gel battery is a gel that binds the water with the acid. While the batteries are being filled, the gel is heated and liquefies. After the battery has been filled with the liquefied gel, the gel cools and solidifies.

This process results in tiny hairline cracks in the gel between the plates.
During the charging process, oxygen O_2 is generated on the positive plate and hydrogen H_2 on the negative plate. The cracks in the gel let the gases combine to create water. The gel then absorbs the water so that no water disappears from the system and no gases are produced.

Gel batteries are not a new technology and have been in use since the late 1950s. The most important applications are in emergency power systems, telecommunications systems, power supply and, for the last 20-25 years, as service batteries in various systems. Gel batteries come in two different versions. The 12 Volt design is appropriate for regular use and available in capacities up to 200 Ah.

The second design is a 2 Volt traction battery, available in capacities up to 2700 Ah and highly suitable for systems with frequent and significant dischar-ging where a long lifespan is needed. For a battery of 12 or 24 Volt, six or twelve gel batteries need to be connected in series to provide the required voltage.

Major benefits of gel batteries include very limited self-discharging, the possibility of a short charging time, and the lack of gas production under normal circumstances. All of this makes gel batteries very suitable for heavy cyclical applications.

The AGM battery

A different type of lead acid battery is the AGM (Absorbed Glass Mat) battery. In this model, the electrolyte (water and sulphuric acid) is absorbed into an extremely delicate glass fibre mat. Just like with any other battery, charging generates hydrogen gas and oxygen, which are transported through the capillary tubes of the glass fibre mat. Once the two gases are recombined, water is once again obtained and subsequently reabsorbed into the glass fibre mat. The recombination process is then complete. The glass fibre mat also serves as insulation between the plates, allowing the plates to be close together and leading to very low internal resistance. This means that a high discharge current is no problem. The charge current could be a little lower than with gel batteries (approx. 30%) because the glass fibre mat is also an efficient heat insulator, and heat generated by charging is gradually conducted to the outside of the case. This requires the charge current to be somewhat restricted and results in a slightly longer charging time. AGM batteries are highly suitable for applications requiring a high discharge current, such as a bowthruster or winches and for medium cycle use.

The AGM battery is entirely closed and therefore maintenance free. If the AGM battery is overcharged, for instance due to the use of a (cheap) unregulated battery charger, a small amount of hydrogen gas is formed. This gas escapes through a special vent in the battery casing that is designed to prevent oxygen from entering the battery. Incorrect charging will reduce the battery's lifespan.

The Lithium Ion battery

Mastervolt's Lithium Ion batteries are based on Lithium Ion iron phosphate, which has an energy density of three times higher than that of lead acid batteries. Although there are materials with an even higher energy density, these are generally considered less safe. Mastervolt's Lithium Ion batteries are the safest batteries of their kind. A unique feature is their built-in Battery Management System (BMS). The system controls cell voltage and temperature, and guarantees optimal safety. Lithium Ion batteries are MasterBus compatible and up to 15% more efficient than lead acid batteries.

This gives you:

- Shorter charging times.
- Less generator time required for charging.
- More power than from a traditional battery of the same dimensions.
- A normal open lead acid battery, for example, has a DOD (depth of discharge) of 50%. This means that you can only use up to 200 Ah from a 400 Ah battery. A Mastervolt Lithium Ion has a DOD of 80%, almost 60% more usable battery capacity. With this percentage, a battery of 400 Ah supplies 320 Ah, or 120 Ah more.
- Lithium Ion batteries are also ideal for electric and hybrid propulsion. Mastervolt Lithium Ion batteries can be paralleled up to ten units.
- Another benefit is that Lithium Ion batteries weigh less and require less space.

Conclusions and recommendations

- The low internal resistance of AGM batteries makes them highly suitable for powering winches, windlasses and bowthrusters, for starting engines, and for limited cyclic use.
- Gel batteries are very suitable as service batteries due to the fact that they can be quickly charged and have a long lifespan, even with many charge/discharge cycles
- For a service battery you can choose for either a 6 Volt, 12 Volt or 24 Volt version or the 2 Volt model.
- Mastervolt batteries are completely maintenance free and in normal circumstances do not release acid or generate dangerous gas. They are easy to install anywhere onboard, such as next to the bilge or in the engine room (reduced lifespan due to higher temperatures). Special battery cases or external ventilation is usually unnecessary as natural ventilation will suffice.
- Lithium Ion batteries save up to 70% in space and weight, last three times longer and can be recharged and discharged very quickly, 2000 charge cycles is no exception.

Determining lifespan

The average lifespan of a 12 Volt gel or AGM battery is up to six years if the battery remains unused and is kept in a charged state. After five or six years of float voltage at an average ambient temperature of 25 °C, the battery still retains 80% of its original capacity. Higher average temperatures will shorten the lifespan of the battery. The number of charge and discharge cycles of a 12 Volt battery is strongly correlated to its structure and quality. Mastervolt's 12 Volt gel batteries can take around 500 full cycles of being discharged down to 20% and charged back to full capacity.

Most manufacturers consider batteries to be spent at a remaining capacity of 80%. This does not, however, mean that the battery has to be replaced immediately.

For example, the battery can still be used if only 50% of the battery capacity is actually required.

It is therefore not necessary to replace the battery after six years or 500 full cycles. An average use of seven years is perfectly normal for 12 Volt gel batteries.

2 Volt traction gel batteries

The lifespan for 2 Volt traction gel cells is around 10 to 15 years and the maximum number of full cycles is 1000-1500 when discharging to 20% of capacity. These batteries are therefore highly suitable for larger systems that require intensive use and a very long lifespan.

Lithium Ion batteries

Mastervolt Lithium Ion batteries have a lifespan of more than 2000 cycles, which is three times longer than most standard lead acid batteries.
This can be attributed to a wide range of features including cell management, the negligible self discharge, the absence of 'memory effect' and a discharge to 20%.

Transport

Transportation of Mastervolt gel and AGM batteries

Mastervolt gel and AGM batteries are considered as non-spillable batteries. This means that they can be transported as non-dangerous goods as they are exempt from Dangerous Goods Regulations which cover transport by road, rail, sea freight or air cargo. So they can be sent to any destination in the world quickly and relatively cheaply.

Transportation of Mastervolt Lithium Ion Ultra batteries

Extra care is to be taken for proper transport of Lithium Ion batteries. Mastervolt's Lithium Ion batteries and their packaging have undergone all the required safety testings as prescribed by the United Nations and the transport authorities (both road, rail, sea and air) to achieve this. Below you will find the technical details of what this means.
The Mastervolt Lithium Ion batteries have been tested according to UN Handbook of Tests and Criteria, part III, sub section 38.3 (ST/SG/AC.10/11/Rev.5). For transport the batteries belong to the category UN3480, Class 9, Packaging Group II and have to be transported according to this regulation. This means that for land and sea transport (ADR, RID & IMDG) they have to be packed according to packaging instruction P903 and for air transport (IATA) according to packaging instruction P965. The original packaging of the Mastervolt Lithium Ion batteries satisfies these instructions.

3-Step+ charging

This modern charging technology allows a battery to be quickly and safely charged in three phases (steps).

The first step is the ***BULK PHASE***, in which the battery is charged quickly.
The output current of the battery charger is at maximum (100%) during this phase and the battery voltage depends on the charging degree of the battery. The duration of this phase depends on the ratio of battery to charger capacity, and on the degree to which the batteries were discharged to begin with.

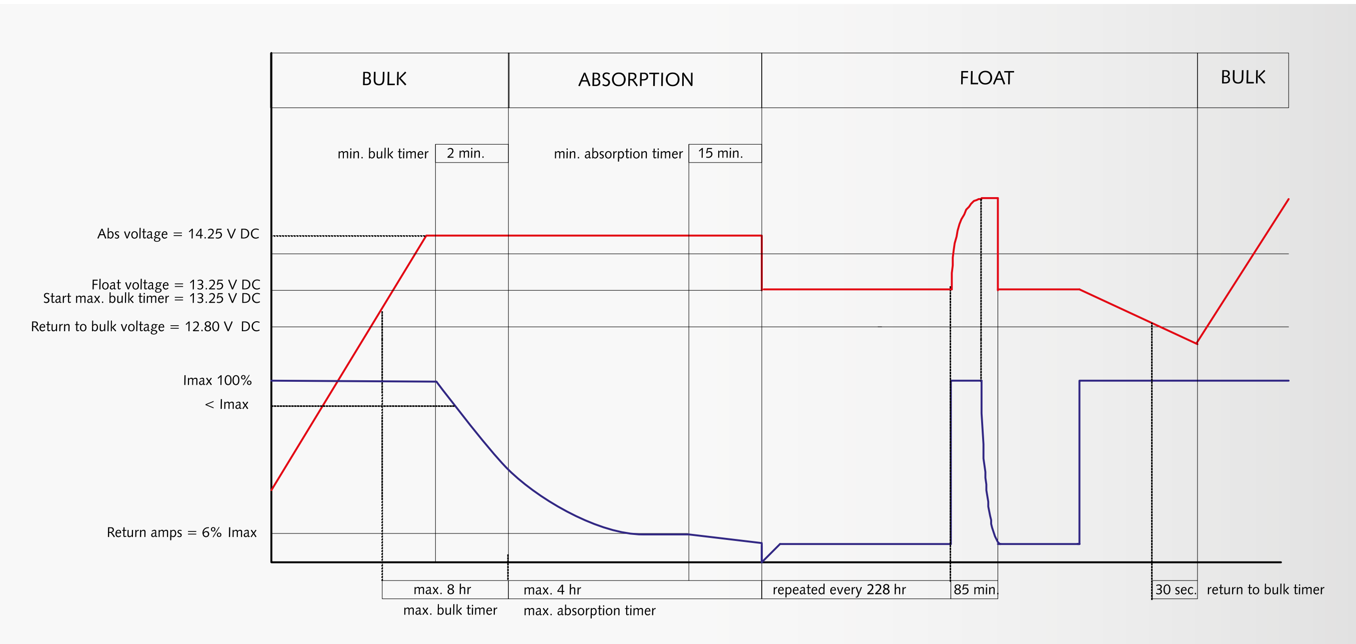
The bulk phase is followed by the ***ABSORPTION PHASE***, which begins once a battery has been charged to ± 80% (90% for gel and AGM batteries), and ends when the battery is completely full. Battery voltage remains constant throughout this stage, and the charging current depends on the degree to which the battery was initially discharged, the battery type, the ambient temperature, and so on. With a wet battery this phase lasts some four hours, with gel and AGM batteries around three.
This does not apply to Lithium Ion batteries as these are charged to 100% with full current.

Once the battery is 100% charged, the Mastervolt charger automatically switches to the ***FLOAT PHASE***.
In this step, the batteries are kept in optimal condition and the connected users are supplied with power. If power consumption is higher than can be supplied by the battery charger, the remaining power is supplied by the battery. The battery is then (partly) discharged and the charger automatically switches back to the bulk phase.
If consumption is reduced, the charger will start charging the battery again via 3-step+ charging. A battery charger with 3-step+ charging can remain connected to the battery, even in winter, and ensures a long lifespan for your batteries as well as being safe for the connected equipment.

Absorption time

The duration of the second phase in the charging of a battery. The battery will, in general, be charged from 80 to 100% during this phase, which lasts around four hours with a wet lead battery, and three hours with gel and AGM batteries. With Lithium Ion batteries the absorption time is very short as they can be charged to 100% with full current. This phase is automatically set for Mastervolt battery chargers.

3-Step+ charging characteristic (IUoUo)



Charge factor

The charge factor indicates the efficiency of a battery. The efficiency of the average wet battery is approx. 80%, which means it must be recharged 1.2 times the eventual capacity in Ah to get the same capacity. This translates into a charge factor of 1.2. The lower the charge factor or the higher the battery efficiency, the better the quality. Mastervolt's gel and AGM batteries have an efficiency of > 90% and a low charge factor of 1.1 to 1.15 and offer the very best quality.

Discharge factor

This is also known as Peukert's Law, and allows you to determine how long a battery can be used at a given load before it needs recharging.

Cycle

A battery only lasts a certain number of charge/discharge cycles, depending on its type and quality. In theory one charge/discharge cycle is the process of discharging a battery to 0% of capacity and recharging it back to 100%. Twice recharging after discharging to 50% is also one cycle, as is four times discharging to 75% and recharging. A starter battery, for instance, can take around 50 to 80 cycles, which may seem little but is in practice more than sufficient: While the current used for starting an engine is high, it only lasts a short time and represents 0.001 of a cycle. In other words, an engine can be started 80,000 times before a battery is worn out. A high-quality semi-traction battery lasts for around 250 to 300 cycles.

If the battery is only discharged to 50% of capacity, 600 cycles are available. Assuming 25 weekends of sailing (50 days) plus 20 days of holiday and discharging only to 50%, the battery will go through 70 half cycles or 35 full cycles.

Charging batteries

Charge voltage

Gel (12 and 2 Volt) and AGM (6 and 12 Volt) batteries need to be charged with a voltage of 2.4 Volt per cell at a temperature of 25 ºC. For a 12 Volt battery set, this corresponds to 14.4 Volt, and for a 24 Volt battery set to 28.8 V. The maximum time that a battery can be charged at this voltage is four hours, after which the voltage has to be reduced to 2.2 Volt per cell, or 13.25 and 26.5 Volt, respectively. Lithium Ion batteries need to be charged with a voltage of 29.2 Volt for a 24 Volt system and 14.6 Volt for a 12 Volt system. The float voltage is 26.5 and 13.25 respectively.

With emergency power systems, where gel batteries can be in float condition for long periods of times (years), the float voltage needs to be slightly increased to 13.8 and 27.6 respectively at a temperature of 25 ºC. Mastervolt supplies DC-DC converters that regulate the onboard voltage to a lower level (13.8 or 27.6 Volt) thus ensuring that (halogen) lamps do not fail during charging.

The charge current

A rule of thumb for gel and AGM batteries states that the minimum charge current should be 15 to 25% of the battery capacity. Connected equipment usually also needs to be powered during charging, so include the power used for that purpose in the abovementioned figure. This means that, with a battery set of 400 Ah and a connected load of 10 amps, battery charger capacity has to be between 70 and 90 amps in order to charge the battery in reasonable time.

The maximum charge current is 50% for a gel battery and 30% for an AGM battery. For a Lithium Ion battery the charge current can be the same as the capacity. A 180 Ah Lithium Ion battery, for example, can be recharged with 180 amps.

The charge system

Ensuring the longest possible lifespan for gel, AGM and Lithium Ion batteries requires a modern battery charger with 3-step+ charging and a sensor for measuring battery temperature. These battery chargers will constantly regulate charge voltage and charge current and adapt the charge voltage to the battery temperature.
As there is always equipment onboard such as refrigerators that draw power from a battery even when it is being charged, a maximum charge voltage has been set to protect the connected appliances. This maximum is 14.55 Volt for a 12 Volt system and 29.1 Volt for a 24 Volt system, which is also the charge voltage applicable at an ambient temperature of 12 ºC.
Mastervolt's modern battery chargers come with a temperature sensor for attaching to the battery, which allows the charger to automatically regulate the charge voltage in accordance with battery temperature. Adjusting voltage to high or low temperatures is not necessary with Lithium Ion batteries.

In order to prevent premature failure of the battery, the ripple voltage of the battery charger has to stay below 5%. If the battery also powers navigation or communication equipment such as GPS or VHF, the ripple voltage must be less than 100 mV (0.1 Volt) or problems may occur with the equipment. Another advantage of a low ripple voltage is that onboard power systems will not be damaged if a battery pole is corroded or incorrectly attached. A low ripple voltage even allows the charger to power the system without being connected to a battery.

Mastervolt chargers are, of course, all equipped with an excellent voltage regulation that keeps ripple voltage below 100 mV. For GMDSS (Global Maritime Distress Safety System) systems onboard larger ocean-going vessels, the battery charger also can be equipped with an amps and voltmeter plus an alarm contact. The alarm contact is connected to the ship's alarm system so that any interruptions to the operation of the charger – due to a cut in the 230 Volt supply, for instance – are detected on time. The optional Mass Charger Interface makes Mass chargers very suitable as GMDSS chargers.

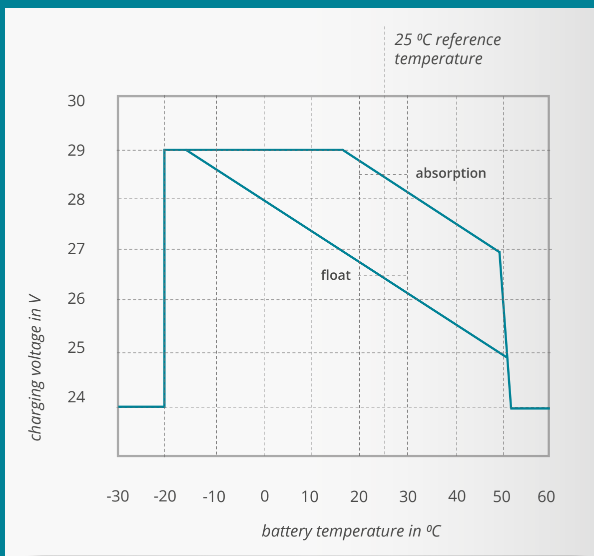
Calculating charging time

Various factors have to be taken into account when calculating the charging time for a battery.

The first consideration is battery efficieny. With a standard wet battery, efficieny is about 80%. This means that 120 Ah has to be charged into the battery in order to be able to draw 100 Ah later. With gel, AGM and Lithium Ion batteries the efficieny is higher - 85 to 90% - so there is less losses and charging time is shorter compared to wet batteries.

Another issue that has to be considered when calculating charging time is the fact that the last 20% of the charging process (80-100%) takes ± four hours (this does not apply to Lithium Ion batteries). In the second stage, also known as the absorption phase, the battery dedicates how much current it needs to absorb independently of the output of the battery charger.

The amount of power depends on the type of battery (wet, AGM, gel or Lithium Ion) and other factors such as the extent to which it was charged to begin with, temperature, lifespan and the ambient temperature.



Temperature compensation curve

The following formula can be used to calculate the charging time of a gel or AGM battery:

$$Lt = \frac{Co \times eff}{Al - Ab} + 4h$$

Lt = charging time
Co = capacity drawn from the battery
eff = efficiency; 1.1 for a gel battery, 1.15 for a AGM battery and 1.2 for a wet battery
Al = battery charger current
Ab = consumption of the connected equipment during the charging process

Taking a battery that is discharged to 50% and applying the example of a 400 Ah gel battery and an 80 amps charger, charging up to 100% will take:

$$Lt = \frac{200 \times 1{,}1}{80 - 10} + 4h \approx 7h$$

Checking the remaining capacity of a sealed AGM or gel battery

The simplest way to check the remaining capacity or condition of a battery is with an Ah meter, such as Mastervolt's MasterShunt or BTM-III battery monitor. In addition to charge and discharge current, the monitor also tracks battery voltage, the number of amp-hours consumed and how much longer the battery has before it needs recharging. The device also provides data on how often the battery has been discharged and to what extent, with both the average and highest discharge level shown. The MasterShunt is easy to connect to the MasterBus network and, with its integrated system clock combined with command-based events, you can program the system to your preference.

A different but very imprecise method of checking your battery is to measure the voltage, which can only be done when the battery has not been used (discharged) or charged for at least 24 hours. While measuring voltage provides a rough estimation of how discharged a battery is, small variations in voltage make an accurate digital voltmeter essential.

remaining battery capacity	battery voltage
25%	between 11.7 and 12.3 Volt
50%	between 12.0 and 12.6 Volt
75%	between 12.1 and 13.0 Volt
100%	between 12.6 and 13.35 Volt

This method is only 15-20% accurate and gives a rough indication of the power remaining in the battery.

Peukert's Law

On the surface it seems easy to calculate how much longer a battery will continue to supply sufficient power. One of the most common methods is to divide battery capacity by discharge current. In practice, however, such calculations often turn out to be wrong. Most battery manufacturers specify battery capacity assuming a discharge time of 20 hours.
A 100 Ah battery, for instance, is supposed to deliver 5 amps per hour for 20 hours, during which time voltage should not drop below 10.5 Volt (1.75 V/cell). Unfortunately, when discharged at a current level of 100 amps, a 100 Ah battery will deliver only 45 Ah, meaning that it can only be used for less than 30 minutes.
This phenomenon is described in a formula – Peukert's Law - devised more than a century ago by the battery pioneers Peukert (1897) and Schroder (1894).
Peukert's Law describes the effect of different discharge values on the capacity of a battery, i.e. that battery capacity is reduced at higher discharge rates. All Mastervolt battery monitors take this equation into account so you will always know the correct status of your batteries.

Peukert's Law does not apply for Lithium Ion batteries as the connected load will have no effect on the available capacity.

The Peukert formula for battery capacity at a given discharge current is:

$$Cp = I^n t$$

Cp = battery capacity available with the given discharge current

I = the discharge current level

n = the Peukert exponent = $\dfrac{\log T2 - \log T1}{\log I1 - \log I2}$

T = discharge time in hours

I1, I2 and T1, T2 can be found by carrying out two discharge tests. This involves draining the battery twice at two different current levels.

One high (I1) - 50% of battery capacity, say - and one low (I2) - around 5%. In each of the tests, the time T1 and T2 that passes before battery voltage has dropped to 10.5 Volt is recorded. Carrying out two discharge tests is not always simple. Often, no large load will be available or there will be no time for a slow discharge test.

Ventilation

Under normal conditions, gel, AGM and Lithium Ion batteries produce little or no dangerous hydrogen gas. The little gas that escapes is negligible. However, just like with all other batteries, heat is generated during charging. To ensure the longest possible lifespan, it is important for this heat to be removed from the battery as quickly as possible. The following formula can be used to calculate the ventilation required for Mastervolt battery chargers.

Q = 0.05 x I x f1 x f2 x n
Q = required ventilation in m^3/h
I = maximum charge current of the battery charger
f1 = 0.5 reduction for gel batteries
f2 = 0.5 reduction for closed batteries
n = number of cells used
(a 12 Volt battery has six cells of 2 Volt each)

Returning to the example of a 12V/400Ah battery set and an 80 amps charger, the minimum ventilation necessary will be:
Q = 0.05 x 80 x 0.5 x 0.5 x 6 = 6 m^3/h

This air flow is so small that normally natural ventilation will be sufficient. If the batteries are installed in a closed casing, two openings will be needed: One on the top and one underneath. The dimensions of the ventilation opening can be calculated using the following formula:

A = 28 x Q
A = opening in cm^2
Q = ventilation in m^3

In our case, this amounts to 28 x 6 = 168 cm^2 (around 10 x 17 cm) for each opening.

Lithium Ion batteries do not produce any hydrogen gas and are therefore safe to use. When batteries are charged quickly there is some degree of heat production, in which case the above formula can be used to remove the heat.

Contact your installer for larger systems with multiple battery chargers.