

Motor Vehicle Starter Batteries

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9.1 THE EUROPEAN MARKET

Lead-acid starter batteries are used in land, sea, and air vehicles. Batteries for vehicles are discussed in this chapter. The production of starter batteries approaches 60 million pieces. About 16 million pieces are used for motor vehicle production and about 38 million pieces keep the vehicles ready for operation as back-up batteries. A considerable number of imported and exported pieces play a part in this market. With these numbers Europe achieves about two-thirds of the U.S. production. The production in the Pacific area is in the range of the European market. Markets with growth expectations are within the area of the former eastern block countries, the countries of the Middle East, India, China, and South America.

The collection, processing, and reuse (recycling) of used motor vehicle starter batteries form an important business activity. The regulation of these activities in favor of environmental protection is done via the national versions of European directives, the used battery regulations, and trade restrictions for the distribution of used batteries in non-OECD countries (Basler list*).

*The Basler list of hazardous wastes is part of the 1992 OECD regulations known as the “Basel Convention” banning the uncontrolled movement of hazardous wastes.

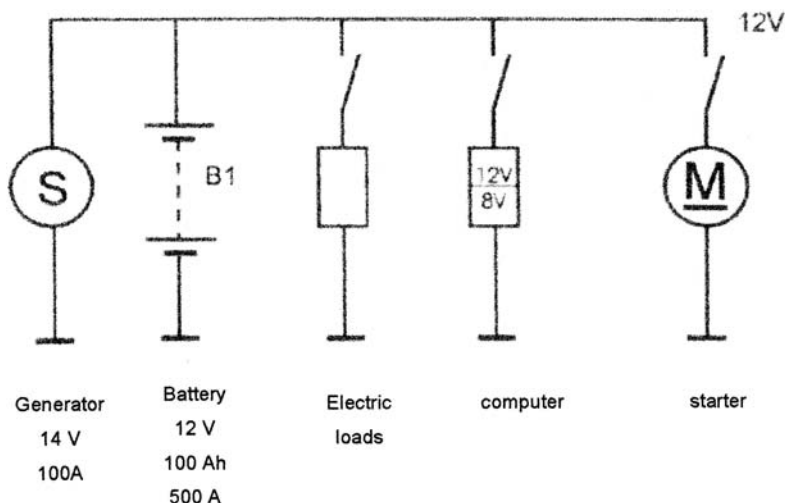


Figure 9.1 The board-net from a motor vehicle in schematic layout.

9.2 TASKS OF A MOTOR VEHICLE STARTER BATTERY

The functions result from the following description of the electrical system of a motor vehicle, the board-net (Figure 9.1). The activation of the system requires that the battery spends the energy for the starter engine and the computer electronics, including preheating or igniting. Security and important auxiliary systems are continuously supplied up to the total discharge of the battery.

The current consumption of a starter battery varies for a very broad range of electric current demands of the board-net in the engine and generator off-state between 10 mA to 50 mA. In the engine idle state and during creep speed, for example, 20 A to 70 A from the battery are needed and the engine start requires, for example, 300 A for 0.3s to 3s. A 12-V 62-Ah battery results in the following specific charge of the electrode plate surface:

		Operating voltage
Board-net supply, 1	$20 \mu\text{A}/\text{cm}^2$ (10^{-6} A)	12 V
Board-net supply, 2	$20 \text{mA}/\text{cm}^2$ (10^{-3} A)	12 V
Engine ignition	$0.5 \text{A}/\text{cm}^2$ (10^{-1} A)	9–11 V

As storage for electrical energy, the starter battery is also a consumer in the board-net. The state of charge depends on constructive features, physical/chemical laws, and a possible regulation in the rank order of the board-net consumers during limited energy production by the generator.

9.3 CONSTRUCTION OF A VEHICLE STARTER BATTERY

Figure 9.2 shows the basic structure of a motor vehicle starter battery, consisting of a container of high-impact-resistant polypropylene copolymer and positive and

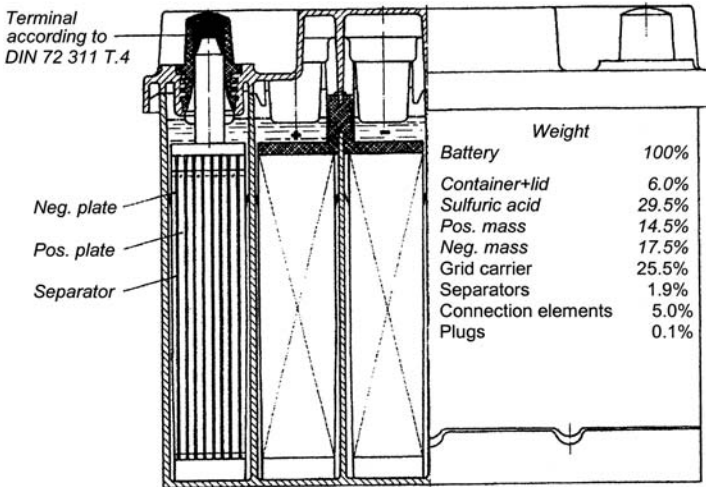


Figure 9.2 Construction of a vehicle starter battery.

negative plates in the cells connected in parallel. Separators electrically separate the plates of different polarity.

Figure 9.3 shows examples of basic grid structures which carry the active masses, with examples of size and the alloy composition. Metallurgists describe the characteristics of alloys made out of different metals by phases or temperature/concentration diagrams. Within these, the formed phases are located; metal components of different constitutions and physical condition are described depending upon the composition and temperature.

Examples of lead-antimony and lead-calcium alloys show the phase diagrams in [Figures 9.4](#) and [9.5](#). In practice the influences are substantially more complex, because of additional alloy compounds beyond binary alloys.

At the lead grids, as a carrier framework of the lead-acid battery for the active masses, two requirements are placed:

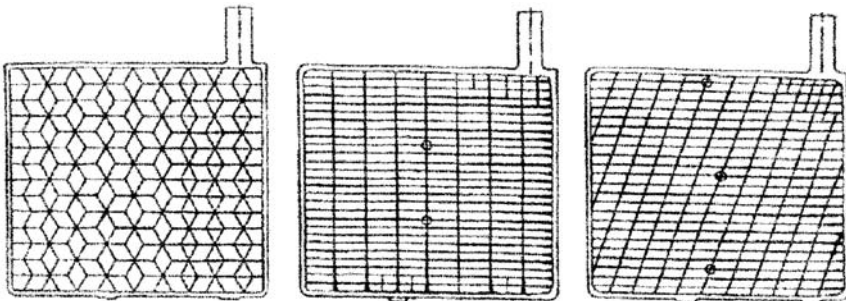


Figure 9.3 Different grid structures that contain the active masses.

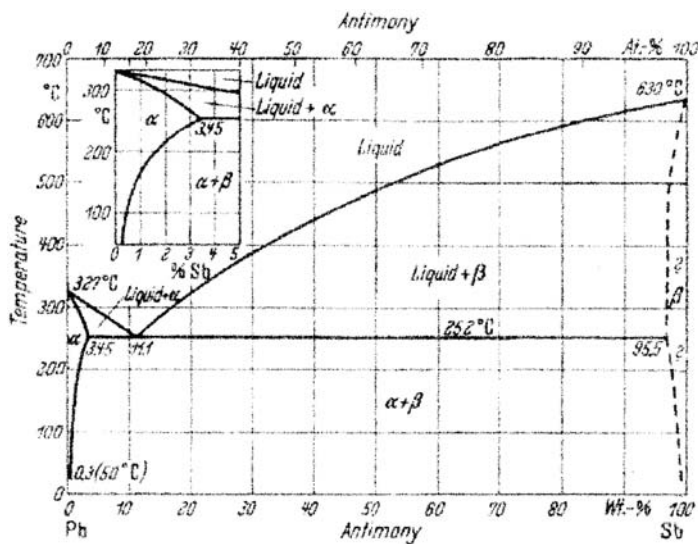


Figure 9.4 Phase diagram of a lead-antimony alloy.

- A mechanical stability depending on the manufacturing methods.
- A sufficient corrosion resistance of the grids for the positive electrode, under the influence of lead dioxide and sulfuric acid.

Optimization of alloy composition, casting parameters, and subsequent treatment provides the required characteristics.

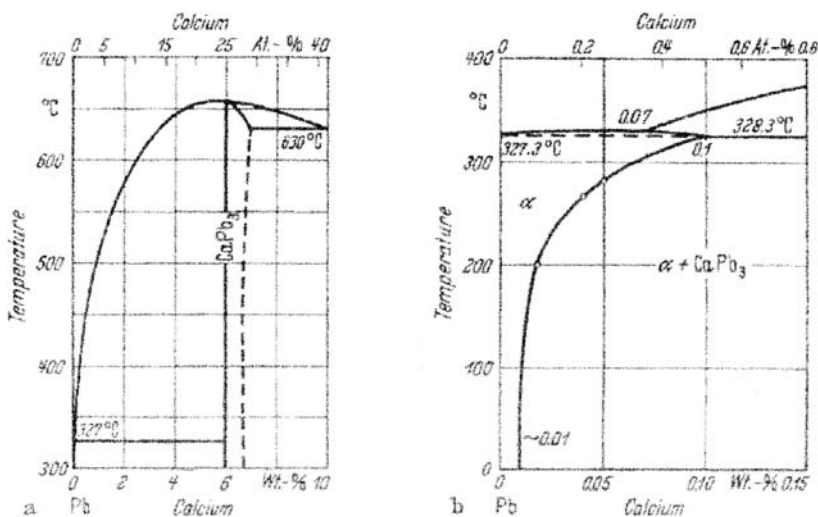


Figure 9.5 Phase diagram of two different lead-calcium alloys.

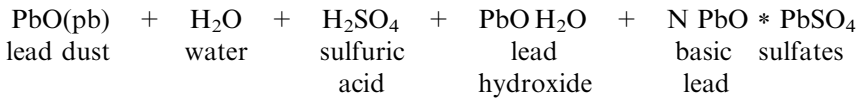
9.4 ACTIVE MASSES OF THE ELECTRODES

The paste-like lead oxide masses, which are applied on the grids, consist of lead dust (25% dispersed lead and 75% lead oxide (PbO)) produced out of the basic material soft lead. The production takes place in ball mills from the solid state or in reaction containers from the molten state.

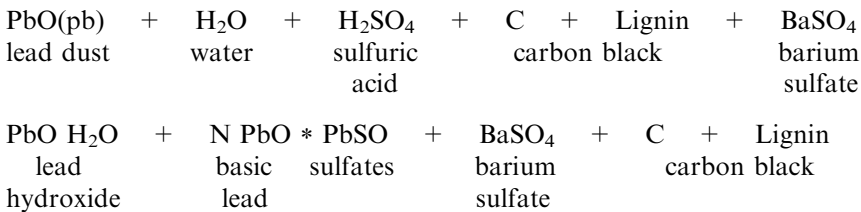
The further processing of the lead dust must be coordinated with the process providing correct particle size distribution in order to obtain the desired electrochemical characteristics of the active masses.

Positive and negative paste compositions will be described in the following:

Positive paste:



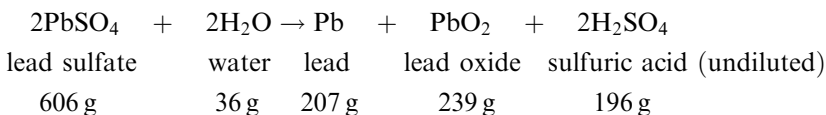
Negative Paste:



9.5 THE MANUFACTURING PROCESS

After applying the porous lead oxide masses on the carrier grids and a superficial drying, the plates are stapled and supplied to a curing process. Within this a control loop of plate moistness and temperature providing the crystal phase formation. The crystal size and plate microstructure are formed out of lead oxide and basic lead oxides. These then essentially determine the desired electrochemical battery characteristics by the resulting pore structure and pore surface. Afterward the plates can be formed, that is the lead oxide masses are electrochemically formed into the active porous positive lead oxide (PbO₂) and the negative lead (Pb) masses by applying direct current. This process is carried out for assembled batteries as well as for plates before the battery assembly process.

In the following the processes with masses and energy quantities are represented:



Theoretical conversion of a cell:

- Energy content: 53.6 Ah.
- Active mass in practice for a 12-V 54-Ah battery:

2400 g Pb; 2600 g PbO₂; 300 g H₂SO₄.

The battery assembly is to a large extent automated. For the electrical separation of positive and negative plates in the sulfuric acid electrolyte, a porous PL foil pocket separates the plates of the same polarity. For the assembly of the cell packages sequences of positive and negative plates are made depending on the desired electrochemical characteristics of the battery.

9.6 DIMENSIONS AND DETAILED SPECIFICATIONS

The following summary shows an overview of the resulting dimensions of the three major production series.

Total number of plates:

Positive plates	Negative plates
N	$N + 1$
N	N
$N + 1$	N

Battery dimensions:

Length (mm)	Width (mm)	Height (mm)	Application
212–381	175	175	Passenger car
212–381	175	90	Passenger car
327–518	175–291	210–242	Truck

Modern motor vehicle batteries are sealed with a lid which offers a central degassing system (Kamina). A more advanced technology solution is a central degassing outlet sealed by a porous plastic frit, preventing the ignition of the oxyhydrogen gas mixture from outside and at the same time the spilling of acid droplets, in combination with a parallel lid wall construction, the chamber lid (duplex).

9.7 MOUNTING POSITION IN THE MOTOR VEHICLE

The placement of the batteries in the motor vehicle presupposes the protection of electronic components from possible sulfuric acid emissions. The electrochemistry of the motor vehicle battery always leads to the formation of oxyhydrogen gas by water decomposition. Therefore, caution is required while handling operating batteries. Burning flames, arc, and sparks of electrostatic loadings ignite oxyhydrogen gas. The necessary ignition energy is extremely small.

The mechanical characteristics of motor vehicle batteries must be determined by the application field of the vehicles. The stress in motor vehicle applications during normal operation for acceleration is in the range of approximately 2 to 3 g. Therefore the tight fit of the plate packages in the cell of the battery container is sufficient.

Aside from road and off-road cars, agricultural vehicles require a much higher effort for the construction of plates and plate packages if a reduced service life

cannot be accepted. For trucks, especially for vehicles for long-distance use on badly maintained roads or for construction and military vehicles, acceleration values up to 15 g can occur at 15 to 30 Hz. Here substantial construction measures must be taken for the plates and plate packages. With these measures the specific energy and efficiency weight of the batteries are reduced (Wh/kg or W/kg).

Motor vehicle batteries are fixed today by retaining strips on the bottom of the battery case or by handle spannings over the cover in the vehicle. Safety demands determine the retaining constructions. The battery must neither be destroyed nor torn from the mounting plate by sudden stopping.

9.8 ELECTRICAL PROPERTIES

The electrical characteristics of motor vehicle batteries are specified in general for the common 12-V nominal voltage in ampere-hours for the energy content and in amperes (A) for the power output as functions of the temperature and the state of charge (100%). The charge current acceptance often appears as an important characteristic as a function of temperature, state of charge, and charging voltage.

The dependence of the energy content of a battery on its discharge current must be emphasized. The usual specification in ampere-hours is related to 20 hours, for example:

$$\frac{100 \text{ Ah}}{5 \text{ h}} = 5 \text{ A}$$

It results for a total energy withdraw over 5 h of

$$\frac{100 \text{ Ah}}{5 \text{ h}} \cdot 0.8 = 16 \text{ A}$$

and not 20 A. The possible discharged energy content decreases to 80 Ah. In the same way the energy content is affected by decreasing temperature.

9.9 STANDARDIZATION OF BATTERY CHARACTERISTICS

General requirements and tests of lead starter batteries and the details of electrical and mechanical examinations which are to be carried out for motor vehicle starter batteries are described in DIN EN 60 095-1:1993. It emanated from the international standard IEC95-1:1988 and is valid in the EU and associated countries.

9.10 NEW DEVELOPMENT REQUIREMENTS

The demands for increased fuel savings make it necessary to improve the efficiency factor of the consumers, the alternators, and the intermediate storage of electrical energy in vehicles.

Increasing luxury features raise the energy demand on vehicle batteries compared to present batteries. It is required that surplus energy of the alternator can be stored by the batteries and lacking energy be drawn; in principle, this is not new. The standard criteria of a modern starter battery are consequently valid for all new board-net batteries. These are

- High energy content.
- High cold cranking power.
- Vibration-proof compared to present starter batteries.
- Deep discharge behavior.
- Low self-discharge.
- Maintenance-free over the whole service life.
- Operating temperature range between -30°C and $+70^{\circ}\text{C}$.
- Series availability.
- Costs comparable to today's batteries.

Since the load on batteries is increased in an optimized board-net and new loads are added, the batteries must be designed to meet these requirements. Start-and-stop systems already require manifold starting impulse power as compared to conventional vehicles.

9.11 VALVE-REGULATED LEAD-ACID BATTERIES

The increased loads in new cars show that the requirements mentioned cannot be fulfilled over a sufficient lifetime by present starter batteries in hybrid or PbCa technology. The requirement to be maintenance — free during the whole service life can only be fulfilled by a valve-regulated lead-acid (VRLA) battery. The high impulse power with the required potential shows that in the valve-regulated technology only the version with micro-glass-fiber separation (AGM) can be applied. This means a lead-acid battery where the electrolyte is fixed in a resistant glass fiber fleece by absorbing the sulfuric acid. A diagram comparing it to conventional systems is shown in [Figure 9.6](#). While in the conventional system the gasses oxygen and hydrogen are generated at the end of charge, which escape from the cell and thus cause the water loss of a battery; the oxygen is internally recombined in the valve-regulated system. Hence a valve-regulated battery is maintenance-free over the full service life – and owing to the fixed electrolyte also independent of its position. A self-closing valve can reduce any overpressure.

Both the positive and negative grids in this new generation of board-net batteries consist of a PbCaSn alloy in order to obtain a high hydrogen overvoltage which is the basis for the recombination and for the extremely low water loss. In addition, the use of this alloy leads to low self-discharge and long shelf-life. The key element of this battery is the fleece separation, a micro-glass-fiber fleece, which fulfills the separator function and at the same time retains the electrolyte because of its high capillary activity.

By using the entire cell volume and a voltage-optimized cell design with optimized grid structure and centrally positioned lug, VRLA batteries can be produced which, compared to standard starter batteries, have a substantially higher cold cranking power in the same container. As a result the cold cranking power at -18°C could be increased from 4.05 kW to 5.2 kW at point U_{30s} in comparison to the present starter battery in the size H8 container.

The advantages of the VRLA series are particularly obvious under cyclic load. Under comparative laboratory test conditions the cycle number achieved against today's sealed starter batteries could be increased by on factor of 3 ([Figure 9.7](#)) [4].

The properties and special features of the VRLA battery can be summed up as follows:

• lead-sulfuric acid battery with fixed electrolyte

• basic structure of a valve regulated cell in comparison with an flooded cell

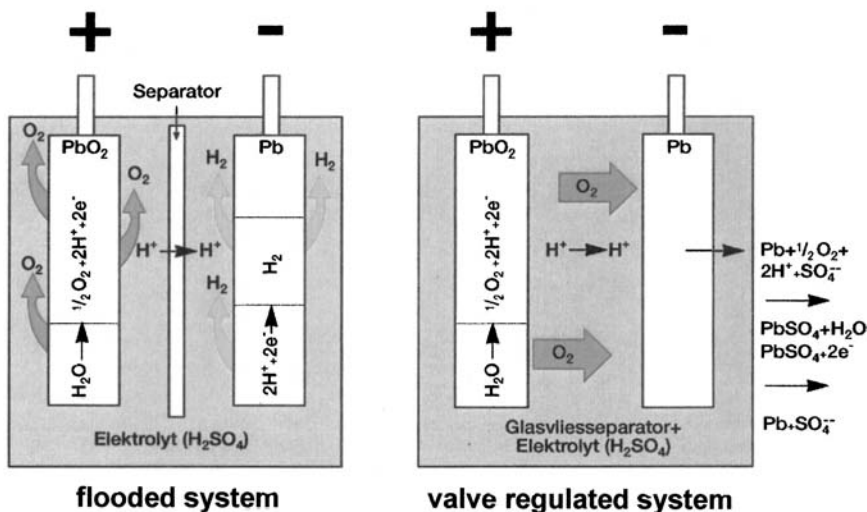


Figure 9.6 Comparison of a flooded system and a valve-regulated lead-acid system in a lead/sulfuric acid battery with fixed electrolyte.

B-samples:

- L5 container (28 kg)
- 950 Wh at 50 W
- cold cranking > 6 kW at -25°C, 80% SOC > 27 V

tests carried out at the present point:

- constant power loads
- charge / discharge cycles in broad frequency range
- start/stop, boost, recuperation
- life cycle tests under consideration



prepared for energy management

Figure 9.7 Results of endurance tests of two 12-V 95-Ah batteries for passenger cars.

- Completely maintenance-free, no inspection expenditures.
- Battery is tilt- and spill-proof.
- Increased safety, no electrolyte escape.
- Low self-discharge, long shelf-life.
- Position-independent assembly easily carried out constructively through fixed electrolyte.
- Reduced explosion potential owing to O_2 recombination.
- Increased energy flow rate – prolonged life and/or savings of weight and volume compared to today's starter batteries.

9.12 TRENDS AND REQUIREMENTS FOR NEW BOARD-NET BATTERIES

Front window heating, electrical steering and braking systems, crank-shaft alternator, as well as electromagnetic valve control are being discussed in connection with the 42-V board-net. The new starter/alternator systems facilitate a feedback of braking energy into the board-net. On the other hand the starter can also be used as a boost function for accelerating the vehicle. The battery in such a board-net must be able to provide the necessary cold cranking capacity and the respective impulse capacity for the boost function, and on the other hand to take up the respective alternator energy. The requirements of the 42-V board-net are listed in Figure 9.8.

Boost functions, start-stop, recuperation, and other specific load profiles in a 42-V board-net have to be evaluated with regard to service life and durability, since current power, pulse duration, temperature, standing times, as well as charging voltage and charging durations have a considerable influence on the life span.

The required features of new board-net batteries listed in Figure 9.8 clearly indicate that the advanced battery generation must be specially distinguished by a higher energy throughput rate as compared to today's batteries.

The dual voltage board-net presents the possibility of an optimum adaptation of each battery according to the electrical demands. In this case the 36-V battery

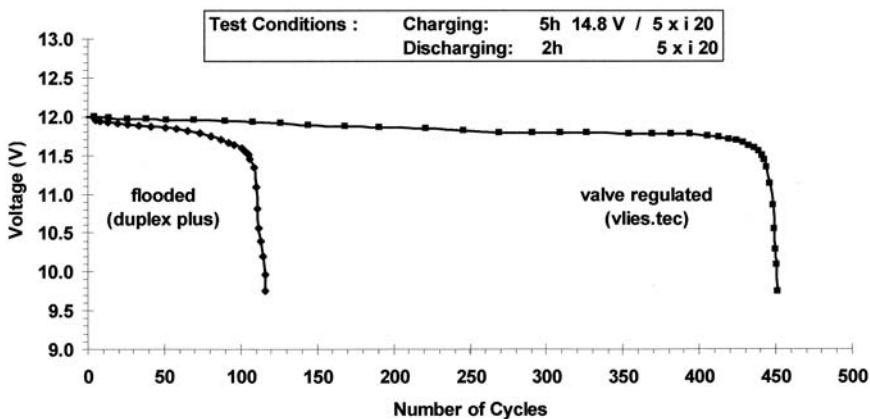


Figure 9.8 Requirements for advanced board-net battery systems.

could be optimized to a cyclically loaded power battery (P), and the 12-V battery to a cyclically loaded battery for standard and quiescent current consumers (LQ). A diagram of such a board-net is given in Figure 9.9.

In answer to requirements the design features of the 36-V battery are roughly the same as those of a present starter battery with central degassing and integrated flame retardant system. The conception provides a different connection technique to exclude any mix-up with the 12-V battery. The container accommodates 18 cells with direct cell connection through the wall as known from the 12-V techniques. Sketches of the battery are shown in Figure 9.10. The requirements of the battery regarding fastening, dimensions, degassing, and flame retardant features as included in the specification for 36-V batteries are fulfilled analogous to the 12-V VRLA batteries.

9.13 BATTERY SENSOR FOR DYNAMIC ENERGY MANAGEMENT

The knowledge of the state of charge and the state of health of the battery is necessary so that an energy management for future board-nets can release sufficient safeguard measures. The identification of the state of charge is also an absolute *must* for the feedback of braking energy into the battery since a nearly fully charged battery could not take up the current. Based on the parameters current, voltage, temperature, and time and using a battery-specific database, it is quite possible to determine the state of charge and the state of health – here meaning the loss of starting capacity – with sufficient precision. By using various characteristic equations of the battery it is also possible to answer essential questions of the battery in a vehicle, for instance: which requirements the battery can fulfill in the present condition.

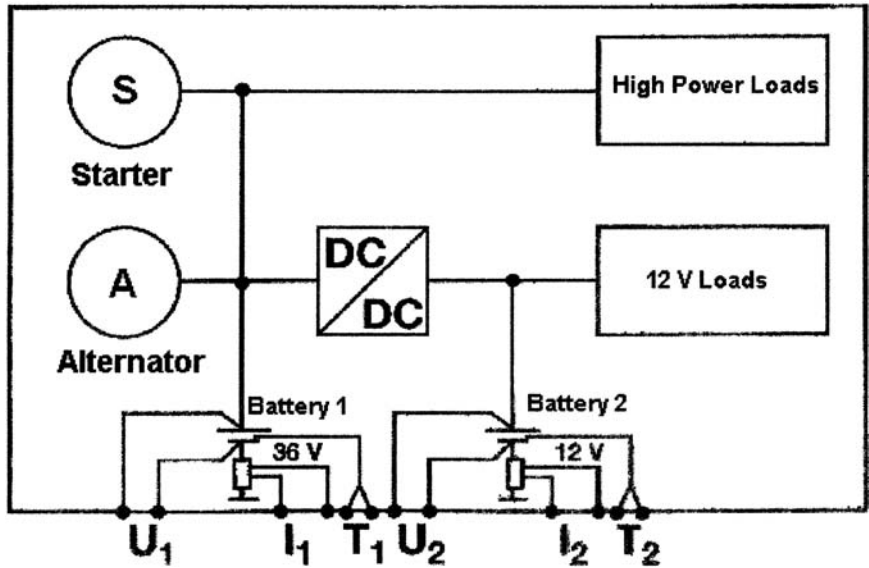


Figure 9.9 Block diagram for the future 42-V/14-V electrical system. Current, voltage, and temperature as a function of time determine the state of charge.

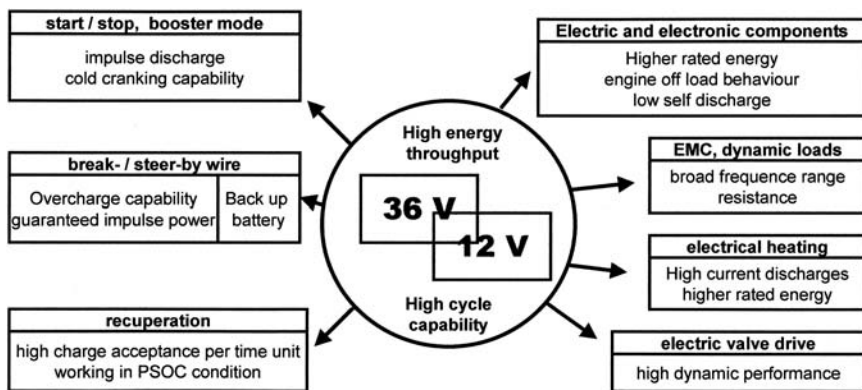


Figure 9.10 36-V valve-regulated lead-acid battery based on vlies.tec[®] 12-V technology.

Consequently, the knowledge of the state of charge (SOC) and state of health (SOH) permits specific and dynamic battery management. This could include consumption control, switching of quiescent and charging current, warning signs, as well as interference into alternator and motor control to increase the state of charge.

REFERENCES

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