# The New 42 Volt System - Basis For High Power Loads And A Possible Step Towards Hybrid Vehicles

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## DEVELOPMENT OF ELECTRICAL COMPONENTS IN ROAD VEHICLES

The power of boardnet systems in road vehicles increased rapidly during the last years. The totally installed power of all electric drives, heating systems and other devices exceeds 20kW for upper class road vehicles (new S-class, DaimlerChrysler: 25kW). The switched-on period of electric loads ranks from a few seconds up to hours. The generator driven by the ICE has to cover the average power. Peak power is delivered by the battery. Due to today's typical battery capacities convenience features like air conditioning in summer or seat heating, windows and mirror defrosting in winter cannot be used before the engine has been started, i.e. the alternator is working.

In which steps have the components of the electric boardnet been developed? In the beginning, the petrol engine only needed an ignition spark and even this the diesel engine could (and can) spare. With the electric starter and electric lighting the 6V-battery was introduced. In the 1960s (especially in 1967 for VW Beetle) the battery voltage was commonly increased to 12V. But ventilation of the Beetle was still connected to the mechanically driven engine cooling fan. Components for more driving convenience or aggregates necessary for operation are up to now mostly driven mechanically (water pump, oil pump, hydraulic pump for steering assistance, etc.). These mechanical drives are mostly connected with high energy losses. One example: Due to the oil pump which is driven by the crank shaft with 3,000rpm the automatic gearbox of the VW Golf has losses of 2.2kW. An electrically driven oil pump with a power of 100W was implemented in this gearbox from Brown Boveri & Cie in 1975. The comment of the development manager of Fichtel & Sachs was "interesting, but electric components in a gearbox?".

Today, in an upper class road vehicle up to 30 motors are installed beginning, e.g. with a pump drive for the headlight cleaning system and ending with the starter. The installed total power of all drives excluding the generator is estimated to 15kW in the year 2005. The number of lighting functions has also increased. An essential further increase of the totally installed power beyond today's 660W is not expected because due to a better light yield a higher efficiency will be reached without increasing the electric power. The power of all electronic units including the engine and vehicle control devices is relatively low. But with almost 300W it already reaches the power of early road vehicles with minimum electric equipment. Electrically heated rear windows were introduced in the 1960s and are standard in modern vehicles. Compared to this, electrically heated front windows are by now standardized only with one vehicle model (AUDI A8). The installed total power reaches more than 1.5kW for the today's heating of rear window, seats, mirrors, etc. For front window heating and catalyst heating further 4kW will be added.

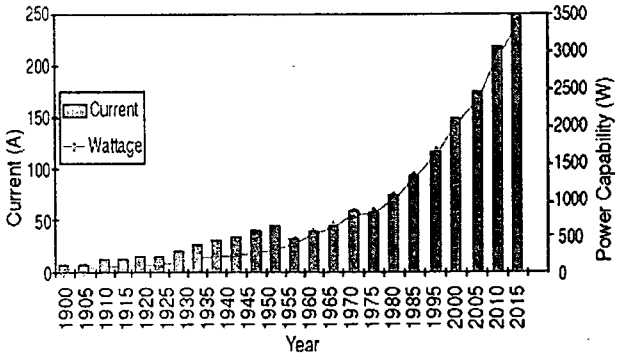


Fig. 1 Consumption of electrical energy and increase of power demand in the boardnet

Today, the boardnet voltage is controlled to the charging voltage of a lead-acid battery 13.8V +/- 0.4V. In general, the upper tolerance range is used. This results in a boardnet voltage slightly above 14V. This value and the three times higher value for the new boardnet voltage of 42V are used in the following to address the voltage levels instead of using the battery voltages 12V and 36V.

## COMPONENTS IN TODAY'S ROAD VEHICLE BOARDNET

One reason for the up to now low boardnet voltage is the low operation voltage of the wire filaments employed in the vehicle's head-lights. These robust filaments are needed to make the head-lights resistant against vibration and shocks. By means of the low boardnet voltage it is also secured that arcs in switches and relays extinguish by themselves. The surface discharges for given creeping and air distances are also very low. Furthermore, employing sufficiently large wire diameters, the voltage drop on the wires can still be kept in the desired range and the necessary plug connectors are well adapted to the line cross sections.

The components of the road vehicle boardnet were at first adjusted to low electrical functions: ignition and lighting.

The first electric drives were used for the starter and the windscreen wiper. The starter motor is considered to be an exception concerning power and battery current because it is driven alone by the battery. The starter current for a modern passenger car reaches more than 500A. For heavy load vehicle engines it was necessary to increase the starter power. This led to the today 28V-boardnet for load vehicles. The limits of the arc voltage and with that the possibility of self-extinction are exceeded with this voltage. Only with large contact distances and double contacts relays it is possible to switch off inductive load circuits. The next large consumer following the starter is the heating. Compared to the starter the heating is switched on over a longer time. Thus, it stresses the boardnet over a longer time. As already said the heating serves partly for comfort but also for safety and environment (e.g. with a catalyst).

The number of electric loads and their control possibility demand intelligent wiring solutions. The number of wires can be reduced by using the CAN bus system which takes over the information. To control the loads semiconductor switches with bus connection are required. The relatively low boardnet voltage of 14V, however, is unfavourable for the use of semiconductors. For the required load power a relatively large current has to be conducted. The system-dependent voltage drop in the semiconductor switch increases the power losses in the switch and drops the entire system efficiency.

As the average power of the boardnet is to be supplied by the alternator this component is the next to be discussed regarding function and efficiency. Although today's alternator power (>2 kW) and even increased power demands in the future are still technically controllable on the 14 V level, this leads to an increasingly uneconomical total system. Therefore, it seems that the limits of the 14V-boardnet are reached.

## INTRODUCTION OF A 42V POWERNET

The conversion of the road vehicle boardnet to 42V (respectively 14V/42V-systems) requires at first high investments and causes a lot of technical and logistical problems. In spite of these problems, in the long term all vehicle manufacturers will have to convert their power supply systems. The additional costs of a new boardnet can only be transferred to the customer if with the new system new functionalities or a reduced petrol consumption will be possible.

The influence of the boardnet on petrol consumption is often underestimated concerning conventional vehicles. Even if the power of the generator in the vehicle seems low in comparison with the IC engine power, however, the maximum engine power of the vehicle is rarely used whereas the maximum generator power is thoroughly necessary and is even exceeded. Thus, the battery is required as an additional storage. In today's boardnets it is assumed that 100W electrical power corresponds to an additional petrol consumption of 0.15l/100km in a typical drive cycle. Correspondingly, the typical average power of a middle class car (ca. 800W) leads to a petrol consumption of 1.2l/100km. One recognizes quickly that with the presently high consumption for the electrical boardnet a 3l-car is hardly to be put into practice.

- **Economization of Consumption:**
  Crankshaft-Starter-Generator, Start-Stop-System, Electrical auxiliary units (Fan, Water pump), Electromagnetic valve drive
- **Advantage of Functionality:**
  Electrical Air-conditioner, Infotainment, Active body control, Heating system
- **Advantages of Safety:**
  Active damping, Brake-by-Wire, Steer-by-Wire
- **Package Flexibility:**
  Systems without Belt drives, Omitted steering shaft, Brake amplifier
- **Quality Improvement:**
  Failure probability, Electromagnetic compatibility

Fig. 2 42V – The new boardnet challenge

There are many reasons for the introduction of a new boardnet voltage. Besides an expected petrol saving through so-called crankshaft starter-alternators through start-stop-systems, electrically driven auxiliaries or through electromagnetic valve control further functionality win is expected for the customer. Used slogans are: electric air conditioning, heated windscreen, infotainment, etc. Furthermore, systems increasing the driving safety, e.g. active damping, active body control and electrical braking and steering systems will also be introduced in road vehicles as soon as a reliable (redundant) 42V supply can be provided. Finally, through the possible complete replacement of the belt drive as well as through an even possible deletion of a stiff steering column there are enormous advantages for manufacturers concerning packaging and crash safety.

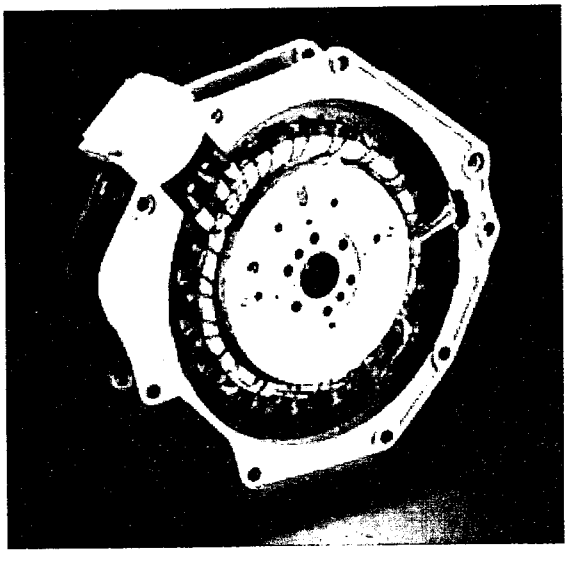

Fig. 3 Crankshaft starter-alternator

Possible net topologies for the introduction of the 42V-powernet are subjects of present discussions. There, a lot of possible intermediate scenarios are presented to limit the amount of changes. These scenarios have both voltages, 14V as well as 42V, in the vehicle. The open question about the topologies preferred in the future results in the up to now unanswered question about the future type of energy storage. In principle, one single (lead) battery on the 42V level (battery voltage 36V) fulfils all the technical demands of most applications in the new PowerNet (excepting the possibly necessary redundancy). However, it could be better to use an additional battery on the 14V level. Both batteries could be differently optimised and could possibly be lighter together than one universal battery which has to fulfil all demands alone.

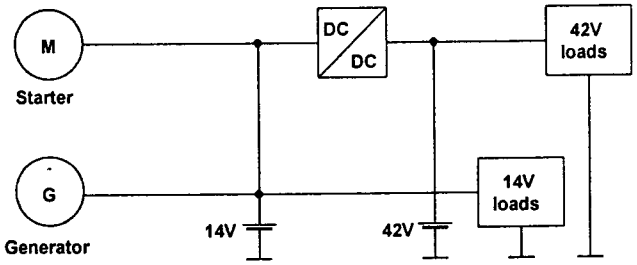


Fig. 4 Starter and generator on 14V level, 42V net fed by a dc/dc converter

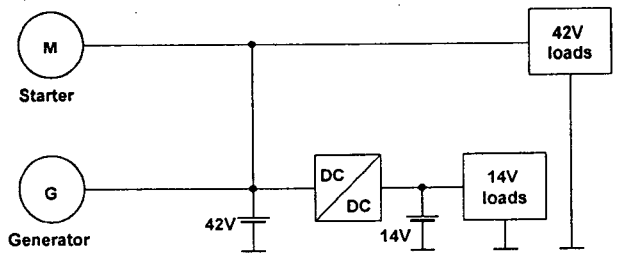


Fig. 5 Starter and generator on 42V level, 14V net with or without battery fed by a dc/dc converter

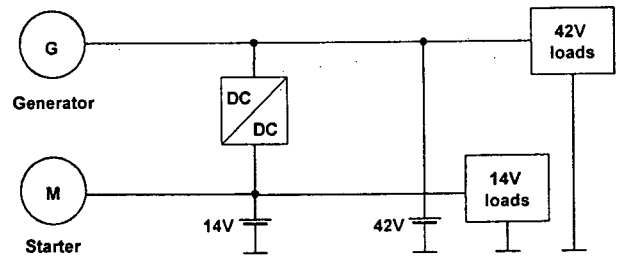


Fig. 6 Generator on 42V level and Starter on 14V. System connected by a dc/dc converter

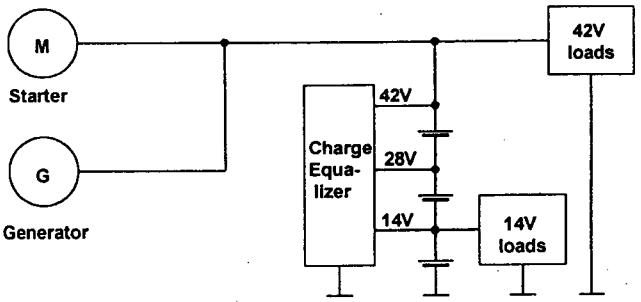


Fig. 7 Starter and generator on 42V level. 14V loads on a part of the battery which is balanced by a charge equalizer

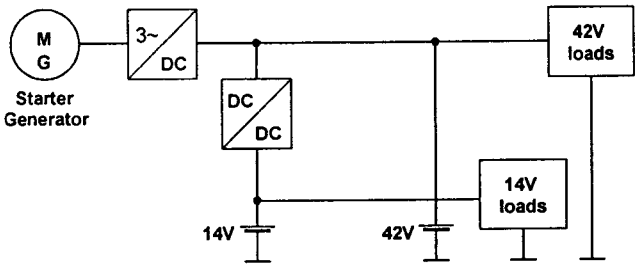


Fig. 8 Crankshaft starter-generator with two boardnet systems

An important criterion for the selection of batteries for road vehicles was and still is the power which a battery has to supply during cold cranking. This is today the most important design criterion for starter batteries. Additional criteria are the energy content at low currents, the charge acceptance at deep temperatures, the possible cycle number dependent of the cycle depths as well as the hence resulting energy throughput. Besides mechanical attributes, above all the stability against vibration and many demands on safety, also weight, volume and costs are decisive selection criteria. Typical data in the today's 14V boardnet are: cold cranking power 4kW, energy content 0.4 - 1.3 kWh, 100-120 cycles for 50% depth of discharge. It is to expect that with the introduction of the 42V powernet the demands on energy storage will increase significantly. Therefore, besides a higher energy density and a better cycle life also higher maximum power, higher charging power and a better charging acceptance even at low temperatures will be required.

If lead-acid batteries can no longer fulfil the demands of the 42V powernet in new vehicles there are advanced storage technologies available, e.g. NiMH- and Li-ion/Li-polymer batteries as well as supercapacitors. However, compared with lead-acid batteries all alternative storage technologies share distinctly higher production costs.

Compared with lead-acid batteries nickel-metalhydrid batteries (NiMH) excel by an essentially increased energy throughput. This great advantage of NiMH-batteries, however, contrasts the relatively high self-discharge rate as well as distinctly limited functionality at extremely high temperatures.

Li-ion and Li-polymer batteries impress with an exceptionally high energy density which is even for power optimised batteries still distinctly ranking above all other technologies. Besides the until today very high price for these batteries, the limited availability as well as possible safety problems and the limited functionality at extreme temperatures have to be mentioned as disadvantages, especially as a disadvantage of Li-polymer batteries.

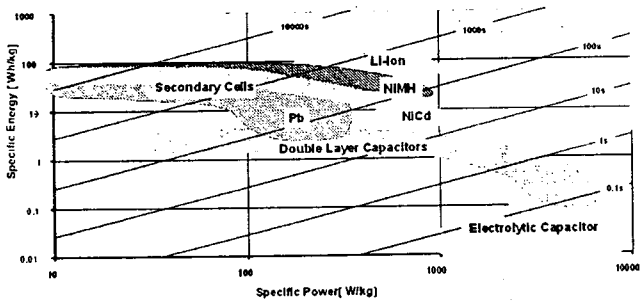


Fig. 9 Characteristics of batteries

Supercapacitors, finally, offer the possibility to distinctly increase once more cycle life and energy throughput as well as power density compared with batteries. On the other hand they have a reduced energy density and a high self-discharge rate. Additionally, the voltage of a supercapacitor decreases roughly linear during the discharge at constant current. This requires additional power electronics for integration of these supercapacitors into the vehicle's powernet.

Where is now the connection between the described developments in the vehicle powernet and the transition from boardnet power to traction? A possible answer can be found when having a look at modern starter-alternator systems. The alternator power of these systems as well as the motor power of crankshaft starter-alternators rise to an extent where old limits between conventional drive technology and alternative (hybrid) drive technology are disappearing. Vehicles where the combustion engine is supported by an electric machine (at a voltage of 42V) are probably to be launched in 2002, they are so-called soft- or mild-hybrid vehicles. Quickly the wish will arise to cover at least short distances without the combustion engine. This wish is already taken into account by the hybrid vehicles Honda Insight and Toyota Prius. Here, a voltage of 42V is no longer sufficient to sensibly realize a motor power in the range of 30kW. If the combustion engine shall disappear and only the electric motor should be used for driving (the source of electric energy might be batteries or fuel cells etc.) a voltage in the range of 400V will surely be necessary. Besides this voltage all other consumers at the boardnet can be run on the 42V level.

## CONCLUSION

A higher boardnet load of future road vehicles could be also fed with a boardnet voltage of 14V with an appropriately sized generator. However, this is not efficient. That is why the boardnet voltage will be increased to 42V in the medium term. When this is about to happen und which vehicle will be the first to be furnished with a real 42V powernet is still unknown. Higher efficiency will be reached by combining starter and alternator and by this the belt drive is dropped. But it is still a long way from the start/stop operation with electric launch assist ("soft- or mild-hybrid" vehicle) to a full hybrid or electric vehicle. Nevertheless, the limits between classic and alternative drive technology seem to be disappearing slowly. Although pure electric traction with a boardnet voltage of 42V is not efficiently possible the launching of the 42V powernet into the mass market of combustion vehicles seems nevertheless to turn to the direction of hybrid drive systems.

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