Journal of Power Sources 105 (2002) 103–109

www.elsevier.com/locate/jpowsour

Battery requirements for 36 V technology

Giuliano Iemmi[a,*], Bruno Dilecce[a,1], Diego Macerata[b,2], Piergiorgio Rena[b,2]

[a]*Fiat Auto-Product Engineering-Electric/Electronic Equipments and Systems-Storage*
System Developments-C.so L.Settembrini, 40-10135 Turin, Italy
[b]*Centro Ricerche Fiat-Strada Torino, 50I-10043 Orbassano, Turin, Italy*

Abstract

According to present evolution trends for ICE vehicles, different architectures of the vehicle electric powernet and improved energy storage systems are required. In particular, the use of a 36 V as nominal voltage for the powernet, in addition to the conventional 12 V one, will be needed to face the increasing power demand caused by fuel consumption reduction needs, comfort and safety concerns. This will require developments in the field of batteries.

In this paper, the trends of development of the electric powernets on conventional vehicles are described along with future system architectures and battery requirements. This last topic includes technical aspects related to the sizing, performance, operating voltage range, technologies proposed, management system and safety concerns. © 2002 Elsevier Science B.V. All rights reserved.

Keywords: Battery; Fuel consumption; Powernet

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1. Scenario

The automobile world will have to face big changes within the next few years, under the impetus of factors, such as market requirements, environment needs and, not least, the fast increase of world-wide energy demand.

The great promise of electrical and electronic devices, both for replacing mechanical functions and for improving the vehicle–user interface, enables the car makers to fulfil two basic requirements: reducing costs and improving product image, simultaneously. The result will be an increase in the number of electric/electronic devices, leading to a higher power demand onboard future vehicles. It is foreseeable that the increase in energy demand for the next few years could lead to a significant fuel price rise.

Moreover, at the Kyoto Climate Change Conference in 1997, the industrialised countries agreed to reduce the average amount of CO_2 emissions by 5.2% (Europe 8%, USA 7%) with reference to the 1990 value. This means that the European Community countries will have to reduce the gaseous emissions taking into account the tendency of a 1.5–2% increase.

However, the expected growth of the automobile market all over the world and particularly in the so-called "emerging countries", will lead to a faster increase of the fuel consumption and consequently environmental pollution. Furthermore, we have to consider the future trend of world population growth, expected to be according to the profile depicted in Fig. 1. Because population will constitute future customers, it is expected to lead to an increase in cars, according to the Fig. 2.

Presently over 600 millions cars are running all over the world. During 1996, the world production of automobiles was 51.5 millions units, most (76%) being produced in the industrialised countries. In future, that percentage will change dramatically because the major growth of the population will occur in the emerging countries, five times more than in the western ones. All these factors will cause a faster increase than forecast of the fuel consumption and consequently of the environmental pollution level.

The energy scenario for the next 50 years, could be outlined on the basis of the following considerations:

1. the world population will grow up to 10 billion people; the number of people in the so called "emerging countries" will constitute over 50% of the world population;
2. as a consequence, the world car inventory will grow six–seven times: from over 600 million automobiles in 2000, up to 3 billions within 2050 and the estimated growth in the emerging countries will reach a rate of 97%;

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[*] Corresponding author. Tel.: +39-11-68-32807; fax: +39-11-68-35672.
E-mail addresses: giuliano.iemmi@fiat.com (G. Iemmi), d.macerata@crf.it (D. Macerata), p.rena@crf.it (P. Rena).

[1] Tel.: +39-11-68-32807; fax: +39-11-68-35672.

[2] Tel.: +39-11-9023-157; fax: +39-11-9023-083.

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PII: S0378-7753(01)00926-0

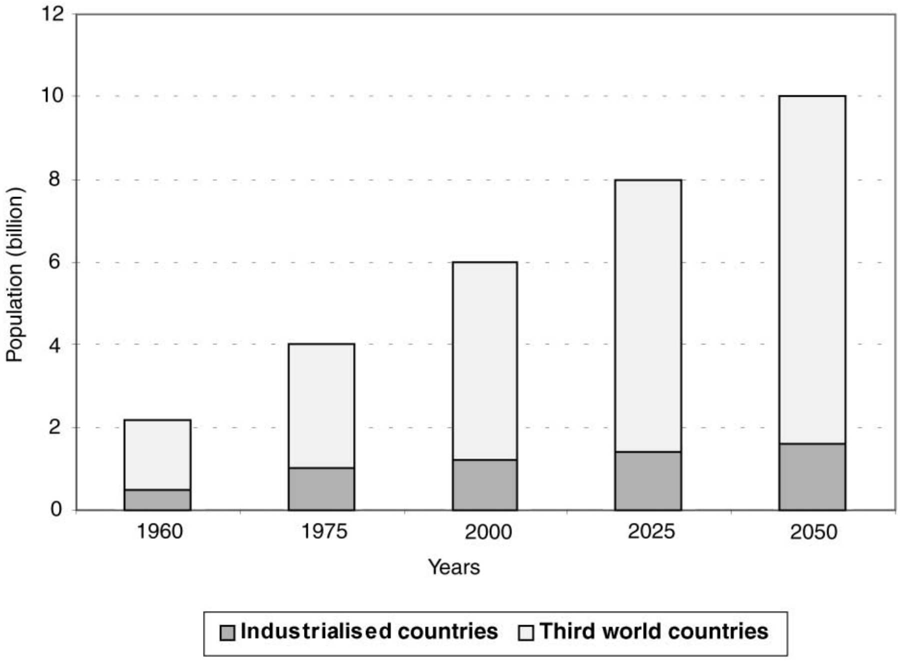

Fig. 1. Growth trend of the world population.

3. according to these trends, the estimated availability of oil could come down from 45 to 30 years (Fig. 3).

Because oil availability trend is estimated on the basis of the assessed reserve, worked at the present costs, a significant fuel price increase has to be expected within the next years and its slope cannot be estimated at the moment.

Important energy saving results could be achieved by optimising the efficiency of the energy conversion systems in automobiles. Engine performance, Cx value and rolling friction coefficient are parameters to be optimised in order to reduce fuel consumption and emissions.

Electrical loads constitute a significant energy amount converted from the primary energy source (the fuel) through the alternator. It is clear that increasing their efficiency will contribute to the fuel savings.

For future cars, which will be equipped with a higher content of electrical devices, the management of electrical loads and the electrical powernet are critical points, subject to strong efforts for optimisation and innovative development, less linked to cost constraints.

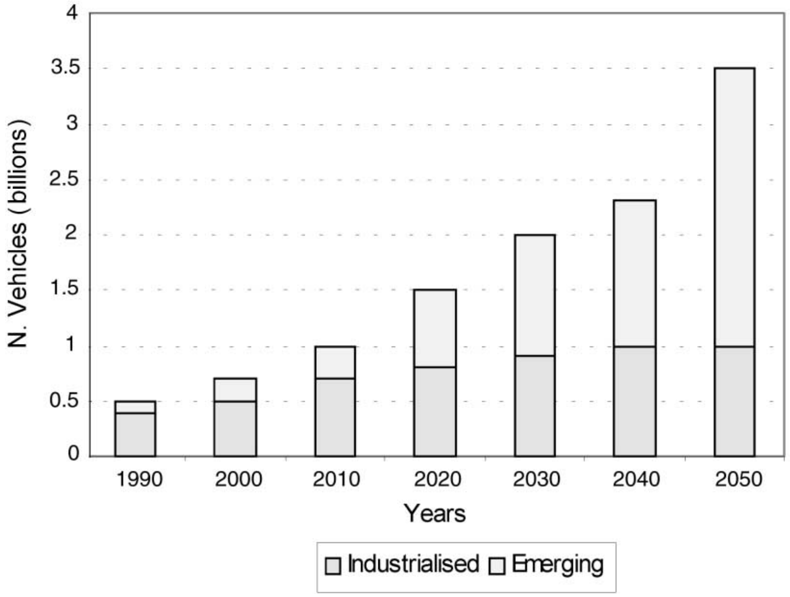

Fig. 2. Growth trend of the running vehicles.

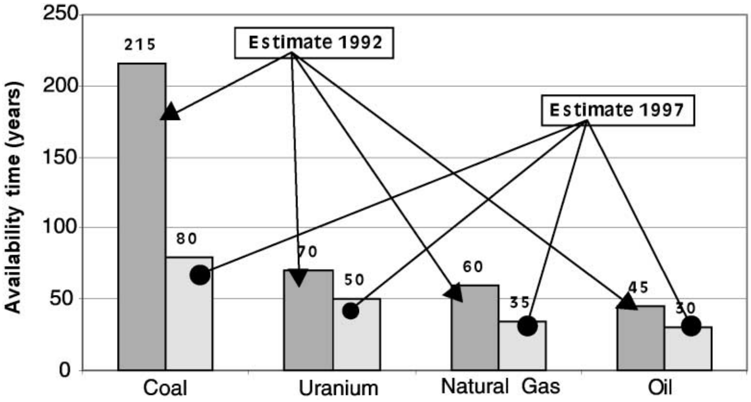

Fig. 3. Energy resources and their time of availability.

2. Trends of development of the vehicles electric powernets

The necessity of reducing the vehicle fuel consumption is having a substantial impact on the design of the new generations of vehicles and in particular on their electric powernet design.

It has been evaluated that a reduction of 100 W electrical power supply by the alternator leads to a fuel saving of 0.14 l/100 km (considering a medium class vehicle as a reference), which is equivalent to a weight reduction of about 50 kg.

There are two other reasons why the vehicle's electric powernet is going to change:

- Improvement of comfort by the introduction of auxiliary electrical loads like heated windscreen, autonomous cruise control and navigation systems.
- Improvement of safety by the introduction of auxiliary electrical loads like tele-diagnosis and service call.

The main electric devices that are going to be introduced or electrified in the future generation of vehicles are listed in Table 1 with their impact on the points listed above. As a consequence, the average and peak power required to supply these electrical loads is going to increase dramatically.

The target to fulfil such power requirements, minimising fuel consumption, can be reached by developing and designing an electric powernet made up of energy saving components and management systems and by adopting a multi-voltage architecture. In such a way, it is possible to get an improved overall efficiency of the electric powernet along with a reduction of weight and volume of the electric components.

The choice of the new voltage levels to be adopted has been discussed in the frame of the main working groups made up by European and American automobile and battery manufacturers (SICAN in Europe and MIT in USA). The following criteria have been adopted:

- voltage values to be a multiple of 12 V, in order to adopt conventional batteries series connected;
- nominal voltage as high as possible; this means lower current values and as a consequence:
  - sizing and cost reduction of the power electronics;
  - optimisation of electrical equipment;
  - voltage drop reduction on the harness;
  - higher efficiency of starting motor and alternator;

Table 1
Electric devices in future generations of vehicles

New electric functions	Consumption	Safety	Comfort
Water electric pump	■		
Oil electric pump	■		
Robotised gear box	■		
Electric power steering	■		
ABS system	■	░	
Pre-heated catalytic converter	■		
Electromagnetic valves control	■		
Electric conditioner	■		
Windshield heater		░	▒
Autonomous cruise control		░	▒
Tele diagnosis		░	▒
Call service		░	▒
Navigator		░	▒

- minimum battery voltage as low as possible;
- maximum powernet voltage but lower than the limits imposed by the safety standards (60 V dc).

Different architectures have been compared:

- architecture with one 36 V battery;
- architecture with one 12 V battery;
- dual voltage architecture with 12 and 36 V batteries.

A comparison among these architectures has been made in terms of electric powernet, fuel consumption and cost; the best option appears to be the dual voltage architecture.

The possibility to use only a 36 V battery without any electronic interface is tied to the possibility to convert the operating voltage of the conventional electrical loads (such as lamps) from 12 to 36 V. In any case, the two batteries (12 and 36 V) will certainly be technologically different from the SLI 12 V batteries presently used.

3. Battery requirements

The requirements for batteries tied to the dual voltage system can be summarised as follows:

- increase of energy and power density in respect to the present batteries; the typical values of the present batteries are shown in the Table 2;
- enhancement of integration flexibility to cope with more and more stringent layout limitations;
- development of modules at 36 V nominal voltage with nominal capacity of 25–50 Ah, optimised with respect to power density;
- optimisation of the 12 V batteries with respect to energy density, within the present range of nominal capacity;
- low internal impedance for the 36 V modules at low temperature (typically less than 20 mΩ at −25 °C to avoid big voltage drops while supplying power to new operational functions;
- cost per Wh and per W at least kept at present levels;
- increase of reliability also for the 36 V modules in spite of the higher number of cells in series;
- increase of cycling ability and decrease of self-discharge rate to reduce the sizing margin which affects the nominal capacity and consequently, weight and volume of the battery;
- ability to withstand an adequate static and dynamic overvoltage;
- development of battery management system (BMS) to maximise the energy system efficiency and to extend the battery life.

Table 3
Dimensional standards for 12 V batteries (dimensions in mm)

EN60095-2	DIN	Length	Width	Height
L0	H3	175	175	190
L1	H4	207	175	190
L2	H5	242	175	190
L3	H6	278	175	190
L4	H7	315	175	190
L5	H8	353	175	190

In the dual voltage configuration, the electrical requirements of each battery may be optimised according to its own characteristic mission profile: the 36 V battery can be designed for a high power discharge rate and the 12 V one for energy.

The possibility to work at a lower current gives the possibility to place the 36 V battery in a different position with in the car. The engine compartment is strongly favoured in the current car assembly mainly for the short cables required to connect the cranking motor and, as consequence, the limited voltage drop due to the electrical resistance of the cable at very high current. Obviously, the high variation of temperature and the high temperature reached in that place are not ideas for a long cycle life of the battery.

To place the battery out of the engine compartment is healthy for the battery and gives also the possibility to change the shape and the size of the battery itself. Nevertheless, in this first phase of the development of the system there are no reasons to change the standardisation of the dimensions. These are linked to the 12 V battery and the locking systems on the car are defined. For the moment the likely dimension is the current standard in EN60095-2 and DIN (Table 3).

The difference between L-series and H-series is very small and it is possible to approximate to the same number. The CENELEC commission is working in order to define the physical and dimensional characteristics. A new reference parameter will be defined relating the size and the capacity.

4. Electrical requirements to 36 V battery

Some operating parameters, such as battery operating voltage limits, as shown in Fig. 4, have been set-up in order to assure the proper operation of the electrical car system in any condition.

Table 2
Typical characteristics of present 12 V batteries

Capacity (Ah)	Fast discharge current (−18 °C) (A)	Nominal voltage (V)	Weight (kg)	Specific energy (20 h) (Wh/kg)	Energy density (Wh/l)	Specific power (W/kg)	Power density (W/l)
50	250	12	12.7	47	87	236	435
100	470	12	24.2	50	103	233	482

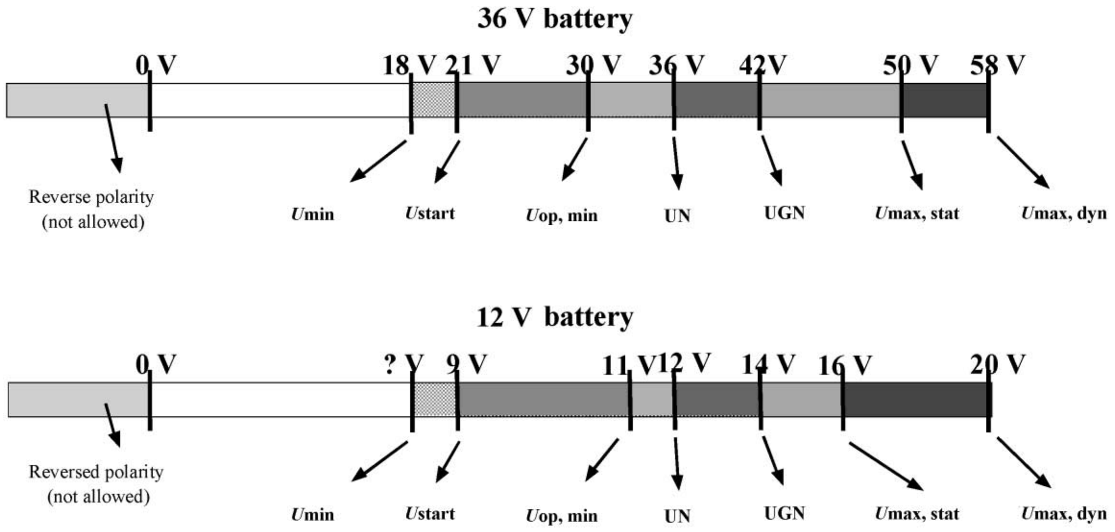

Fig. 4. Electrical requirements of 12 and 36 V batteries.

The definitions of the terms in Fig. 4 are:

U_{min}	Minimum voltage (general). This is the minimum voltage level during the engine start that, according to the starting test pulse, is allowed for no more than 15 ms. According to the current proposal of a short circuit test pulse, a 16 V level for no more than 100 ms could be allowed.
U_{start}	Minimum start voltage. The minimum start voltage is the lowest threshold for the permitted operating voltage at start-up. It represents an effective value, which includes possible ripple at start-up. The voltage is measured at the battery terminals.
$U_{\mathrm{op,\ min}}$	Minimum value of the operating voltage. This is the lowest threshold for the operating voltage. Full functionality of all 42 V loads. Exception: loads required at start-up and safety-related loads.
UN	Battery nominal voltage.
UGN	Generator nominal voltage.
$U_{\mathrm{eff\text{-}max,\ stat}}$	Effective value of the maximum static over-voltage.
$U_{\mathrm{max,\ stat}}$	Maximum static over-voltage. Maximum static over-voltage (including ripple) in a 42 V vehicle electrical system. Peak value of the generator voltage including ripple, irrespective of transient format.
$U_{\mathrm{max,\ dyn}}$	Maximum dynamic over-voltage.

5. Battery technologies

5.1. Lead batteries

The lead technology is the most consolidated and spread because of its maturity and low cost, surely it will be still the main product for many years. The battery manufacturers are putting efforts especially to improving the specific power targets, due to the increasing request for high power applications. This may be obtained by modifying the grid and the electrode design, by making them thinner than those of high energy batteries. Spiral wound batteries seem to be particularly interesting. They are made up by electrode strips spirally wounded: the thinness of the electrodes and their extended surface allow to increase substantially the specific power rate. This is achieved at the expense of the specific energy.

In particular, special characteristics required of a 36 V lead batteries are:

- medium capacity value (25–50 Ah);
- high discharge power density, also at low temperature;
- high recharge capability, especially at low temperature;
- limited state-of-charge (SOC) operating window;
- low cost.

The immobilisation of the electrolyte in an adsorbed glass mate (AGM) battery allows to increase both the specific power and the life cycle of the battery with respect to the flooded type. Other comparative characteristics of the AGM batteries are:

- no spillage;
- maintenance free during life-time;
- high cold cranking power (+30%);
- improved charge acceptance;
- good recovery capability from deep discharge;
- vibrations proof;
- improved cycling capability.

The combination of the electrode design optimised for the high specific power and the AGM technology would allow a battery to comply with the requirements of the 36 V systems.

5.2. Lithium batteries

The main advantage offered by lithium batteries is the single cell voltage, which is in the range between 3 and 4 V as a function of the electrode materials (Li ion or lithium metal at the anode, manganese oxide, nickel oxide or cobalt oxide at the cathode); this means higher specific energy and higher reliability due to the lower number of cells to be interconnected to make up a 36 V system.

The main characteristics of lithium batteries are:

- very high energy density;
- good high rate discharge and recharge capability also at low temperature and in a wide temperature range;
- no acceptable side reaction in the cells, especially during charging; for this reason a battery management system monitoring each single cell is essential to avoid over-charge and over-discharge conditions that may lead to permanent battery damages;
- excessive high temperature can shorten the battery life;
- long-term durability and calendar life is still to be proven;
- costs higher than lead batteries.

Different lithium battery technologies can be investigated, using different materials for anodes, cathodes and electrolytes. The lithium battery with polymeric electrolyte would have been preferred for safety reasons, but for the moment industrial development plans, seem to favour liquid electrolyte technology.

As has been done for the lead batteries, high power lithium batteries are under development for 36 V and hybrid applications. In general, the development of this technology is presently mainly focused on the safety issues; in particular, the research of less reactive materials preventing the battery from being damaged in case of over-charge, over-discharge or internal short circuit (that may lead to a fire). At the same time, a reliable battery management system must be developed to avoid misuse of lithium batteries.

6. Battery management

The real innovation in the field of the 36 V storage systems for automobile applications is the need of a BMS; independently from the technologies adopted, the BMS is the most important device to control the battery operation and to keep its operating SOC within a proper range, in order to maximise system energy efficiency and to extend battery life. Through the measurement of the most significant battery parameters it is possible to detect abnormal operating conditions and to prevent the battery from operating in over-charge or over-discharge conditions by operating the system components control. In the case of dual voltage configuration, the battery management system might be included in the dc/dc converter system, in order to optimise the energy flow between the two batteries.

The main functions of the BMS must be:

- measurement of the main battery quantities (voltages, current and temperatures);
- estimation of battery SOC, which requires the knowledge of the electric circuit model for the battery;
- estimation of the battery state-of-health, which requires a model of battery ageing;
- cell balancing (particularly important for the lithium batteries);
- thermal management, the temperature being a key parameter to be managed in order to allow higher battery output, but especially lifetime saving, avoiding damage due to over-voltage in the recharging phase; it can be performed by the BMS through the control of the cooling circuits;
- generator voltage regulation (in relation to the temperature);
- dc/dc converter control.

The BMS is essential for lithium batteries for safety reasons. The characteristics of the lead batteries, which are more tolerant to over-charge and over-discharge conditions, are such as to require a less sophisticated control system. However it is still important to improve their reliability and cycle, life to provide a positive impact on the vehicle maintenance cost.

7. Safety concerns

The application of additional 36 V batteries brings safety concerns. In particular, the main concerns regard:

- to avoid short circuits using tools;
- to avoid casual connections between 12 and 36 V batteries;
- to avoid polarity inversion;
- to control the battery voltages in order to prevent faster discharges through the dc/dc converter.

Terminal standardisation will be required and this is being developed with in the frame of the MIT Consortium. Another goal of MIT group is to establish the interchangeability of battery modules.

8. Conclusions

The automobile world will have to face big changes within the next few years. There arise from competition in the market from environmental requirements and energy constraints.

The increasing of safety and comfort features and especially fuel consumption reduction will feature strong up in automobile development. Higher electrical power will be needed on board the vehicle. The choice to introduce a 36 V battery in the vehicle electric powernet could allow these requirements to be met.

As a consequence, new battery generations fulfilling different mission profiles with respect to the standard SLI ones have to be developed. To save cost, only the lead–acid option is presently available, even though the expected performance, especially in terms of reliability and energy/power density, are presently border line for the system. The development of battery management systems appears very likely in order to solve car failure problems rising from shortcomings of the battery.

Among the innovative systems, lithium batteries represent a promising candidate for future application in the automotive field. But the cost, even in the context of a significant increase of production volumes, appears to be still unfavourable. In order for this technology to take off, the performance/cost ratio will have to be improved.