

## Development of electric systems for hybrid and electric vehicles

**Abstract.** This article presents improvement concepts of automotive electrical systems. 12-volt electrical systems are heavy and not effective for hybrid and electric vehicles. Author of this article performed study of energy consumption to analyze this problem. For this purpose 10 Channel Automotive Ammeter was developed. Current measurements were made in vehicle fuse boxes during test drives and simulation tests. Studies have shown that some circuits are overloaded and incorrectly designed. After summarizing of measurement results, author developed concept of Energy Distribution Controller with integration of Power Rail. This solution combined with 48-volt installations, will allow to developed efficient electric system for hybrid and electric cars.

**Streszczenie.** W tym artykule przedstawiono koncepcje usprawnień w samochodowych systemach elektrycznych. 12-woltowe systemy stosowane we współczesnych pojazdach są ciężkie i nieefektywne dla pojazdów hybrydowych i elektrycznych. Autor tego artykułu przeprowadził badania zużycia energii w pojazdach samochodowych. W tym celu został opracowany 10 kanałowy amperomierz służący do pomiaru prądu w samochodowych instalacjach elektrycznych. Podczas badań symulacyjnych i jazd testowych prąd był mierzony w skrzynkach bezpiecznikowych pojazdów. Badania wykazały że niektóre obwody elektryczne są nadmiernie obciążone i niepoprawnie zaprojektowane. Autor przedstawił koncepcję sterownika Centralnej Dystrybucji Energii z integracją szyny zasilającej. Rozwiązanie te połączone z instalacjami 48-voltowymi pozwoli opracować efektywny system dystrybucji energii dla pojazdów hybrydowych i elektrycznych. (**Koncepcje rozwoju instalacji elektrycznych w pojazdach elektrycznych i hybrydowych**).

**Słowa kluczowe:** Instalacje elektryczne w pojazdach samochodowych, Pomiar zużycia energii elektrycznej w pojazdach  
**Keywords:** Automotive Electric Systems, Measurement of energy losses, Power Rail, Energy Distribution Controller

### Introduction

12-volt installations are currently common in vehicles. This type of electric systems are not effective in cars with high power consumption. The disadvantage of typical installations are also the weight (about 60 kg). The average length of electrical harnesses is approximately 6000 m and depends on vehicle variants. The cost of electrical wires is also high because copper is used as main conductor. Weight and costs shall be reduced by optimizing the construction of electric system.

Author performed energy consumption measurements to analyze this problem. The current measurements were made with using 10 Channel Automotive Ammeter in car fuse boxes. After measurement sessions results were analyzed and summarized. Study of energy consumption done by author confirms also statement that main electric circuits are overloaded. Author has developed concept of Energy Distribution Control Unit with integration of 48 Volt electric system and Power Rail. This solution allows to integrate an effective electric system for hybrid and electric vehicles.

### Measurement of energy consumption

Measurement of power consumption are used to evaluate the effectiveness of the electrical installation. Professional measurement stands are located in laboratories and can simulate the operations of the vehicle electrical system. This method of measurement is very accurate but does not allow analysis of parameters in the vehicle's operation and test drives.

Author has developed a new method for measuring energy consumption with using 10 Channel Automotive Ammeter. This equipment allows to measure current in fuse box and power consumption in mass-produced vehicles without disassembling the components. Fig. 1 shows the schematic of test stand. Test stand includes 10 Channel Automotive Ammeter, Clamp ammeter (optional) and oscilloscope.

Vehicles with complex electrical system were selected for tests. Measurement sessions of energy consumption was performed during laboratory tests and test drives. This methods allows to simulate the operating conditions of the electrical system in different types of vehicles.

Table 1 presents part of measurement results during measurement of energy consumption. Circuit ID, fuse type

and list of electrical equipment are detailed specified in manufacturer technical documentation. The last column presents measured current during tests.



Fig. 1. Vehicle Energy Consumption Stand.

Table 1. Measurement results in automotive electric systems

ID	Electrical Equipment	Fuse Type	I, A
F1S	Engine Control Unit	20 A	3.41
F2S	Horn	15 A	0.10
F3S	Windscreen washer pump	10 A	0.12
F4S	Headlight Washer Pump	10 A	0.09
F5S	Engine equipment, Secondary fan motor	15 A	3.51
F6S	Mass flow sensor, Directional light system	10 A	2.31
F7S	Power steering	10 A	1.15
F8S	Starter	25 A	0.01
F9S	Clutch pedal sensor, Brake pedal sensor	10 A	0.08
F10A	Main fan motor	30 A	8.14
F11S	A/C fan	40 A	6.51
F12S	Windscreen wipers	30 A	0.06
F13S	Body Control Module (BSI)	40 A	5.12
F17S	Low beam right	15 A	3.21
F18S	Low beam left	15 A	3.23
MF1	DC Motor - heating system	50 A	3.12
MF2	ABS system	50 A	2.31
MF4	BSI equipment	80 A	8.12
MF8	Suspension hydraulic pump, Suspension air compressor	40 A	7.16

### 10 Channel Automotive Ammeter

Measurement of power losses in car electrical systems is difficult to perform due to set correct measurement range.

The solution to this problem is to measure the current using an ammeter designed by the author. Most of popular ammeters have too small measuring range (about 20 A). 10 Channel Automotive Ammeter developed by the author can measure the current up to 200 A. This measurement instrument is based on ACS770 Hall effect current sensors which can measure current in wide range.

Advantages of using 10 Channel Automotive Ammeter:

- ability to protect electrical circuits during electrical measurements,
- convenient access to the electrical circuits and harness,
- ability to perform measurements during vehicle operation and test drives

Ammeter Specification is presented in Table 2.

Table 2. General specification of 10 Channel Automotive Ammeter Input Voltage:

Number of measuring channels:	10
Specification of measuring channels:	
TS	Shunt (100 A/75 mV)
CH1	Current Sensor ACS770ECB-200B (200 A)
CH2	Current Sensor ACS770ECB-200B (200 A)
CH3	Current Sensor ACS770ECB-200B (200 A)
CH4	Current Sensor ACS770LCB-100B (100 A)
CH5	Current Sensor ACS770LCB-100B (100 A)
CH6	Current Sensor ACS770LCB-100B (100 A)
CH7	Current Sensor ACS770LCB-050B (50 A)
CH8	Current Sensor ACS770LCB-050B (50 A)
CH9	Current Sensor ACS770LCB-050B (50 A)
Sensor type	Bidirectional
Sampling frequency	0...120 kHz
LCD Display:	
1) Dual segment display	1) TS
2) Graphic display	2) CH1-CH9
Measuring connector	BNC

### Summary of measurement results

After measurement sessions results have been analyzed and summarized. The conclusion is that 12V electrical systems and energy distribution solutions have reached the peak of efficiency. This confirms the fact that complexity of electrical circuits must be optimized. The number of electronic controllers and electrical components has increased in modern vehicles. Load factor level and the weight of electrical installations also must be reduced.

Measurement of the maximum power consumption in the vehicle's electrical circuits was tested in simulations of environmental conditions. During tests heating elements were switched on at low temperatures (e.g. glow plugs, window heating), engine cooling systems were tested at high temperatures (e.g. engine fans, air conditioning). Power consumption measurements were performed by author with using 10 Channel Automotive Ammeter.

Research shows that these electrical circuits are overloaded (Fig.2):

- 1) Starter circuit (up to 260 A),
- 2) Windscreen and mirror heating (up to 18 A),
- 3) Seat heating and control (up to 17 A),
- 4) Actuators and electric motors circuits (up to 15 A),
- 5) Engine cooling system (up to 12 A),
- 6) Hydraulic pump and air pressor in active suspension system (up to 9 A),

7) Fuel heating and heating systems (e.g fuel heaters, glow plugs) (up to 14 A),

8) Vehicle lighting based on halogen bulbs (up to 25 A)

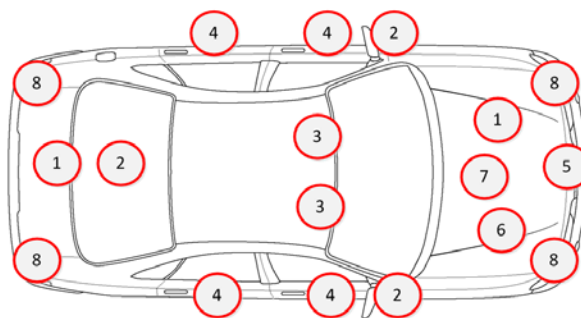


Fig. 2. Main 12 V energy loads in vehicle.

Measurement results have contributed to develop the concepts described in next chapters.

### 48 Volt Systems

The energy consumption analysis presented in this article shows that main 12V circuits are overloaded. The way to optimize energy distribution systems is to use higher voltage level in vehicle electric system. During research made by key automotive companies, it was decided to increase the voltage level up to 48 V. Typical examples where 48V installations can be used are electric motors used in electric window lifts, power steering motors and other actuators that require high power efficiency [1]. Development of 48V components was initiated in hybrid and electric cars.

Components should be designed in a compact form, oversized solutions are not recommended (except safety equipment). It is also a good practice to replace heavy pneumatic and hydraulic systems with electrical solutions. Electric components can be installed in places where they are not exposed to high temperature and humidity, so their life cycle will be increased [2].

After analyzing of these problems, it can be stated that the development of 48V systems and equipment is a good improvement to implement new solutions in electric and hybrid vehicles. 48V systems have also disadvantages that were not previously present. The main problem is the increased incidence of arcing discharge [3]. This problem occurs in the components that switch the circuits on and off, particular case are the integrated relays [4].

### Energy Distribution Control Unit

After analysis of 48V systems, author developed the concept of an extended electrical installation which integrates the 12V and 48V systems. The solution is shown in Fig.3.

The main component of the system is the Energy Distribution Control Unit (4) connected to the bidirectional DC/DC converter (5). The energy sources are lithium-ion batteries (7), 12V lead-acid battery (1) and supercapacitors (6). Additionally it is possible to charge the battery system using an alternator (3) driven by petrol engine (2). Energy Distribution Control Unit functions:

- integration of 12V and 48V systems,
- DC/DC converter control,
- battery charge level calculation
- diagnostics of battery systems,
- battery charging process control,
- charging interface (Plug-in),
- supervision of circuit overload protection using eFuse and regular fuses (redundancy of over current protection),
- cell balancing (active and passive balancers),
- diagnostics of electrical circuits and components.

This concept can be applied to electric and hybrid cars. In electric vehicles, the motor operates as load, but it is also possible to work in a generator mode. In vehicles with petrol engines the alternator works as a source of electric energy. This concept includes cooperation with the efficient lithium-ion cells that during operation require a balancing process. Implementing these features allows to integrate BMS (Battery Management System) with Energy Distribution Controller.

The concept of integrating electrical systems involves the use of conventional lead-acid battery, it is a relatively cheap type of power source and can supply components at low ambient temperatures. Typical process is petrol motor start up (high current efficiency at low temperatures). Components such as electric turbochargers require additional power sources to supply large amount of power in a short time. Author in his concept predicted the possibility of using supercapacitor batteries that could supply energy to selected components. The concept of this system includes the use of additional optional power sources. Example is electric retarder that allows energy recovery from braking. An additional source of energy are also the solar panels that can be used in cars operating in warm climates. The integration of these energy source allows solar batteries to be charged.

The Central Energy Distribution Controller advantages:

- ability to integrate multiple energy sources,
- effective protection of electrical circuits against surges and short circuits,
- possibility to apply concept in electric and hybrid vehicles
- redundancy in energy sources
- diagnostics and active measurement of electrical circuits

Disadvantages of Central Energy Distribution Controller:

- cost of electrical system expansion,
- electric system complication (power sources, electrical components, assembly elements).

In the next part of this article author will describe the integration of this Central Energy Distribution System with Power Rail.

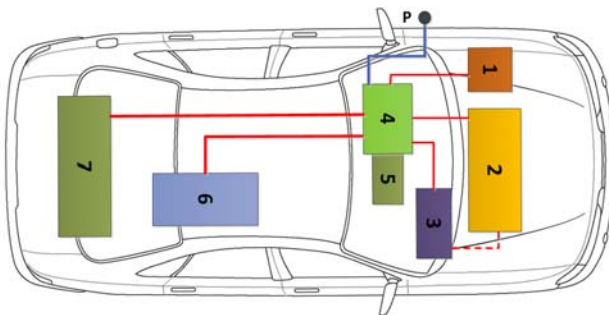


Fig. 3. Concept of power sources decentralization (detailed description in the text)

### Concept of Central Power Rail

The concept of 12V/48V installation includes Central Distribution Controller described in the previous chapter is an evolutionary solution that will improve the electrical systems in modern vehicles. It can be stated that this concept enforces application of Central Power Rail. This solution limits the number of wires and harnesses, weight of complete electric system will be also reduced. The concept developed by the author integrates the central data bus with Power Rail. The rail integrates three or more conductors (+48V, +12V, GND) which are developed for distribution of energy to the receivers.

Power Rail reduces the energy losses. Special contacts with large contact surface can directly power electrical components and equipment. The Central Power Distribution

Controller allows the rail to protection against overvoltage's and short-circuits (eFuse integration). Author's concept allows to integrate the Power Rail with the data bus. Thanks to this solution number of transmission wires and harnesses will be limited. Integration of Power Rail and lithium-ion batteries and can deliver more energy to electric receivers located in vehicle.

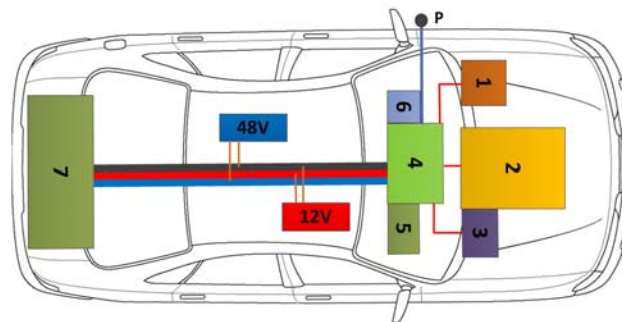


Fig. 4. Power rail integration with Central Energy Distribution System - author's conception:

- 1) Lead-acid battery, 2) Petrol engine, 3) Alternator, 4) Energy Distribution Control Unit, 5) Bidirectional DC/DC converter, 6) Supercapacitors, 7) Lithium-ion batteries, P) Plug-in connector

### Conclusion

This article shows that electrical installations in modern vehicles need to be optimized. Measurement of energy consumption confirms that new solutions in power distribution shall be implemented in hybrid and electric cars. Concept of Central Power Controller developed by author of this article is good solution because this ECU (Electronic Control Unit) can integrate many functions and limits the number of wires and harnesses. Power Rail implementation optimizes energy distribution system and extends the data transfer system.

Implementation of Energy Distribution Control Unit concept will be described in next article after creating of Central Power Controller prototype. The effectiveness analysis of the new proposed solution will be done after laboratory tests and measurement sessions.

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