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Chapter 4

Energy Efficiency of Electric Vehicles

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/55237

1. Introduction

In this chapter, the most important possibilities for increasing energy efficiency of electric vehicles would be considered, regarding energy savings accumulated in the vehicle itself and increasing the range of performances of the cars with given initial resources. Some of the possibilities that should provide such a progress nowadays are:

- Using energy under braking
- Using waste heat energy
- Additional supply by solar cells
- Improved mechanical energy transmission system
- Improved cars shell design
- Increasing of efficiency of power convertors
- Special design of electric engines
- Using supercapacitors, fuel cells and new generation batteries
- Route selection on the criterion of minimum consumption in real time
- Parameter monitoring inside and outside of the vehicle and computerized system control with optimization of energy consumption

Today, the problem of energy becomes so important that an entire industry is turning towards clean, renewable energy (solar energy, wind energy, etc.). Prototypes of hybrid vehicles with the announcement of mass production scheduled for the near future have become everyday occurrence. In addition, many cars are designed to use only electricity as motive power, which reduces emissions to zero.

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Photo cells in a glass roof generate electricity, even at lower intensity of solar radiation; this current operates using a fan in a vehicle. In this way the vehicle interior has a constant supply of fresh air and pleasant temperatures (up to 50% lower), although the motor vehicle is turned off so that fuel economy is evident. The solar roof is only the beginning, while the development of city cars is going toward solar vehicles prototype.

A solar vehicle is an electric vehicle powered completely or significantly by direct solar energy. Usually, photovoltaic (PV) cells contained in solar panels convert the sun's energy directly into electric energy. The term "solar vehicle" usually implies that solar energy is used to power all or part of a vehicle's propilsion. Solar power may be also used to provide power for communications or controls or other auxiliary functions.

Another concept that has been developing over the years is a kinetic energy recovery system, often known simply as KERS. KERS is an automotive system for recovering a moving vehicle's kinetic energy under braking. The recovered energy is stored in a reservoir (for example a flyeheel or a batterry or supercapacitor) for later use under acceleration. Electrical systems use a motor-generator incorporated in the car’s transmission which converts mechanical energy into electrical energy and vice versa. Once the energy has been harnessed, it is stored in a battery and released when required. The mechanical KERS system utilizes flywheel technology to recover and store a moving vehicle’s kinetic energy which is otherwise wasted when the vehicle is decelerated. Compared to the alternative of electrical-battery systems, the mechanical KERS system provides a significantly more compact, efficient, lighter and environmentally-friendly solution. There is one other option available - hydraulic KERS, where braking energy is used to accumulate hydraulic pressure which is then sent to the wheels when required.

Development of new components, improved connections and electric engine control algorithms allow increase of efficiency of power convertors, therefore electric engine itself, to the maximum theoretical limits. New generation improvements of electric engine system has an impact on price, however investment quickly pays off during operating.

Major efforts are invested in the development of high energy density batteries with minimum ESR. Also, current research show that fuel cells have reached needed performances for commercial use in electric vehicles. Supercapacitors that provide high power density increase the acceleration of vehicle as well as collecting all the energy from instant braking, therefore improvements of the characteristics of power supply are made.

Modern electric vehicles have full information system that has constant modifications and does monitoring of inside and outside parameters in order to achieve maximum energy savings. Except for smart sensors, it is highly important to process GPS signals and route selection on the criterion of minimum energy consumption.

By combining these technologies, concepts and their improvements, we are slowly going towards energy-efficient vehicles which will greatly simplify our lives in the future.

http://dx.doi.org/10.5772/55237

2. Electrical losses reduction in EV

2.1. Energy efficiency of the converters

Increasing of the energy efficiency of the convertors can be achieved by optimizing their configuration and control, as well as choosing the adequate component. Converter configuration depends on the type of the electric motor (DC or AC), possible recovery energy braking, drive dynamics etc.

For DC motor supply there are mostly used chopper voltage reducers, so they will be considered here. Figure 7 shows simplified presentation of the chopper supply of a DC motor. Chopper is shown as ideal breaker controlled by voltage (U_{up}), so it can control switching on (T_{ON}) and switch-off (T_{off}) exiting voltage (U_{do}). For all four quadrant operation transistor bridge as shown in fig. 1 can be used [1].

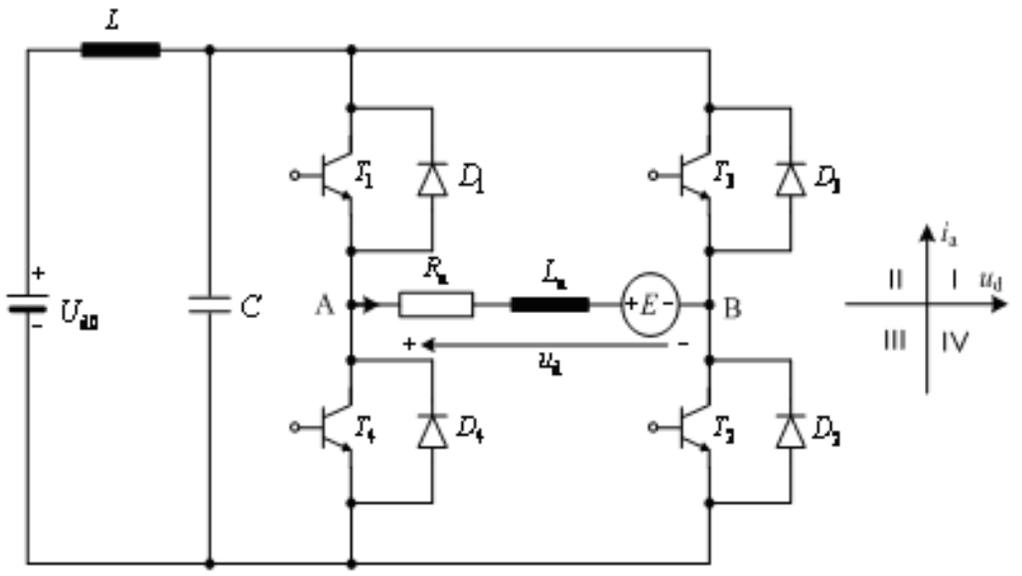


Figure 1. Transistor Bridge

By switching on transistor pairs T_1-T_2 or T_3-T_4 positive or negative polarity of motor voltage u_d is provided. To close motor current at null or reverse polarization, diodes D_1 to D_4 are provided. Converter part of the AC drive of the vehicle consists of the inverters, regulators and control set. The inverter is part of the drive inverter that inverts DC voltage to AC voltage necessary waveform to ensure the required control electric motors. Three-phase inverter consists of three inverter bridges with two switching elements in each bridge, therefore, a total of six switches. By controlling the moments of switching of the particular switches, and by controlling the length of their involvement, the appropriate waveforms at the output of inverter are achieved.

General modern circuit for speed regulation of DC motor is shown in figure 2. Reference rotary speed W_{ref} is set and also maximum armature current I_{amax} and their actual values are monitored and also brought into regulator which outputs present command values for excitation actuators and inductor [1-2].

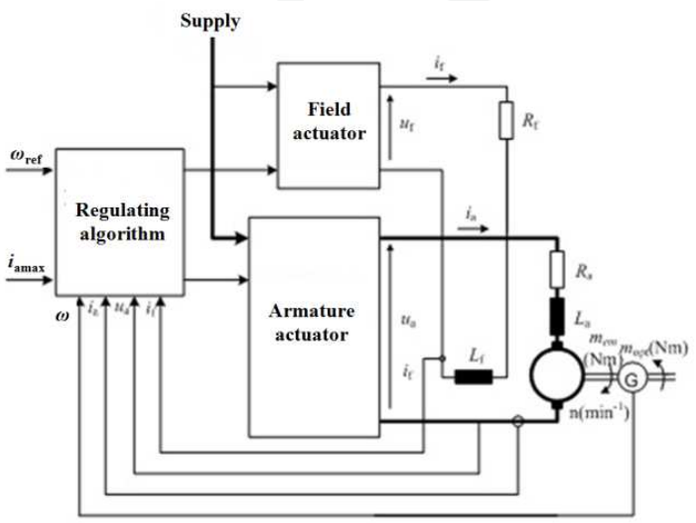


Figure 2. Circuit for speed regulation of DC motor with independent field

Out of base range (for speeds above nominal) method of reduced field is used so among basic values excitation current, i_f, is monitored. Apart from classic PID action, regulating algorithm comprises other tasks (actuator command input adaptation, change of regulating method in accordance with the given speed, alarms etc.). Standard way of regulating DC drives, cascade regulation, consists of two feedbacks: internal – current and external – speed.

Asynchronous motor at constant frequency and amplitude of supply voltage rotor speed depends of load torque, which requires complicated governing algorithms in case when precise speed control and/or position. This phenomenon is a consequence of principle of asynchronous motor, and it is electromagnetic induction, which requires difference in between rotor speed and rotary magnetic field generated by stator to create electromagnetic torque. Electronics that creates algorithms mentioned was expensive earlier and such a use of asynchronous motors was difficult, but today with cheaper electronics components and use of microprocessors for regulating algorithms they are more often used.

Figure 3 represents block-diagram of regulated drive for AC motor. Depending on use and requirements, some of feedbacks and regulators can be left out. Power block (converter + motor) has two input and five output values. Input (command) parameters are effective polyphase supply voltage U_d and frequency Ws. Output (regulated) values are motor current Is, flux w, position O, rotary frequency w and torque me. Each of those has proper regulator in negative feedback, in order as shown in figure 10.

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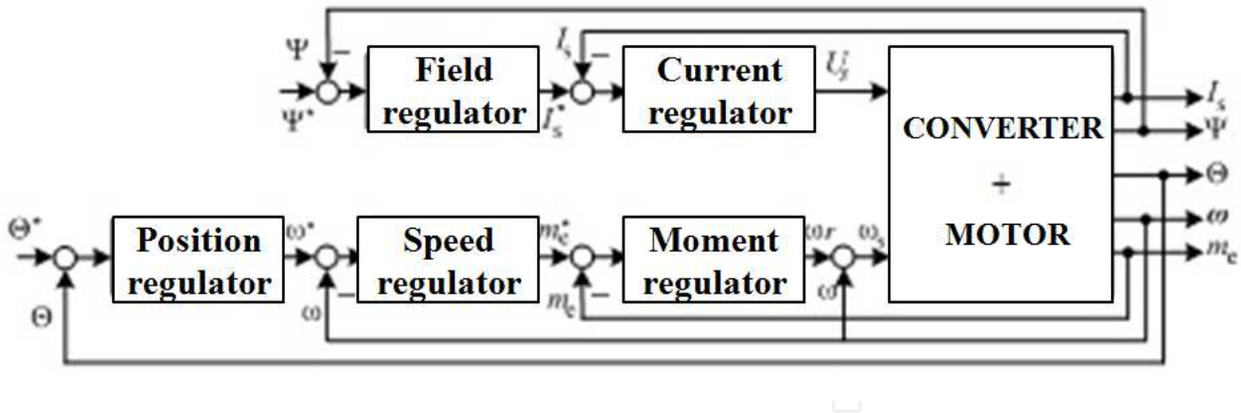


Figure 3. Block diagram of AC motor regulator

Regulation (close-loop control) comprises control with negative feedback, or feedbacks, by means of which, by means of measuring regulated parameters and comparing with required (reference) parameters those values, is acted upon command parameters, so it is automatically achieved ahead defined values of controlled values [1-2].

There may be a large energy saving by selecting the suitable power switching elements, which development is in high prosperity. As switch elements in the inverters and choppers high-power bipolar transistors, MOS (Metal Oxide Semiconductor) transistors or IGBTs (Insulated Gate Bipolar Transistor) are used. High-power bipolar transistors have very low collector-emitter resistance in the conducting state, while their control must provide sufficient supply base, it is required a relatively high power for control. On the other hand, MOS transistors have very high input resistance, and to control them it is just enough to provide the appropriate value of the voltage between the gate and source. Therefore the MOS transistor control current is almost zero and there is no power dissipation in the control circuit. Lack of MOS transistors is relatively high resistance in ON state. IGBT belongs to the family BiMOS transistors and combines these fine qualities of high-power bipolar and MOS transistors [2].

Development of multi-axis distributed control systems where sensors, actuators and controller are distributed across networks. System features system synchronized control and high speed serial communications using fiber optic channels for noise immunity. In addition, communication protocols have been developed that monitor data integrity and can sustain operation in the event of a temporary loss of communication channel. Engineers can design a system to meet exact customer requirements (fig. 4) [2].

In this way, the optimization of the drive by the criteria of the dynamics and energy efficiency, while following the user's request. For supply of certain components, particularly in hybrid vehicles, high power supplies of constant current or current impulses are needed. Precise management and optimization of such sources today is exclusively microprocessor controlled [3].

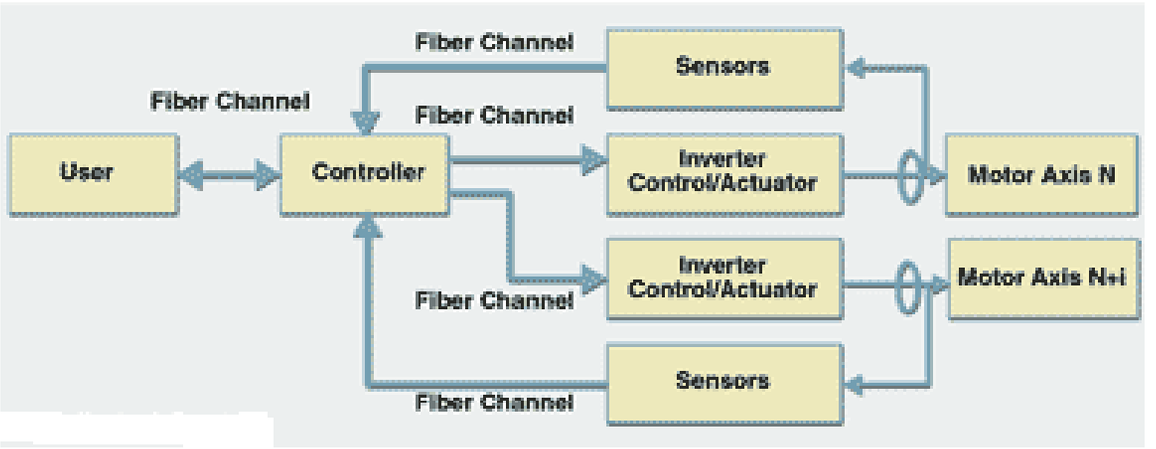


Figure 4. Distributed control

2.2. Energy efficiency of the electric motor

The electric motor is the most important part of the electrical drive and the last link in the chain of energy conversion. DC motors because of their good qualities, control of the rotation speed and control of the torque, for a long time have been irreplaceable part of the controlled electric motor drives. In recent years, thanks to the advanced control techniques, asynchronous motors take place of the DC motors in regulated drives because of its good properties (robustness, lower maintenance requirements and their appliances in explosive environments, which are especially important in the case of hybrid vehicles).

Electric motor drive is designed and optimized starting from the known parameters of the engine. The latest methods for minimizing the power losses in real-time by reducing the level of flux does not require knowing of all engine parameters, and can be applied to asynchronous motor drives with scalar and vector control. Optimization of efficiency of asynchronous motors is based on adaptive adjustment of flux levels in order to determine the optimum operating point by minimizing losses [2].

Losses due to higher harmonics have to be taken into account when determining the degree of efficiency of the entire drive. The voltage at the output of the inverter is considered ideal sinusoidal in the case of control structure developing and the produced effects of higher harmonics are subsequently taken into account.

Any well-designed controller for optimization should meet the following requirements [2]:

- to determine the optimal operating point for each speed and each load torque of the defined areas of work;
- the duration of the optimization process is as short as possible;
- to have a minimum number of sensors required;
- to be easy to use;
- that it can be applied to any standard electric motor drive;

- that it can be applied to any type of engine if the only known data are on motor nameplate;
- to demonstrates a high degree of robustness in the case of disruption load torque;
- Demonstrates a high degree of robustness in the case of motor parameter variations.

Beside the standard electric motors, solutions specially made for EV are developing. Therefore, switched reluctance motor (SRM) is gaining much interest as a candidate for electric vehicle (EV) and hybrid electric vehicle (HEV) electric propulsion for its simple and rugged construction, ability of extremely high-speed operation, and insensitivity to high temperatures. However, because SRM construction with doubly salient poles and its non-linear magnetic characteristics, the problems of acoustic noise and torque ripple are more severe than these of other traditional motors. Power electronic technology has made the SRM an attractive choice for many applications. The SRM is a doubly salient, singly excited synchronous motor. The rotor and stator are comprised of stacked iron laminations with copper windings on the stator, as shown in Fig. 5 [4]. The motor is excited with a power electronic inverter that energizes appropriate phases based on shaft position. The excitation of a phase creates a magnetic field that attracts the nearest rotor pole to the excited stator pole in an attempt to minimize the reluctance path through the rotor. The excitation is performed in a sequence that steps the rotor around.

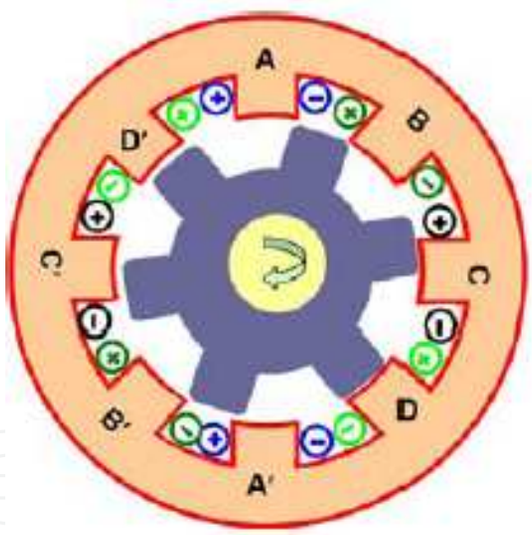


Figure 5. A switched-reluctance motor with 8 stator poles and 6 rotor poles

The SRM is similar in structure to the stepping motor, but it is operated in a manner that allows for smooth rotation. Because there are no permanent magnets or windings on the rotor, all of the torque developed in the SRM is reluctance torque. While the SRM is simple in principle, it is rather difficult to design and develop performance predictions. This is due to the nonlinear magnetic characteristics of the motor under normally saturated operation.

The special design of electric motors used in direct-drive vehicles where the engines are installed in each wheel. This will be discussed more in the mechanical transmission part.

2.3. Supercapacitors vs. accumulator batteries and fuel cells

Supercapacitors are relatively new type of capacitors distinguished by phenomenon of electrochemical double-layer, diffusion and large effective area, which leads to extremely large capacitance per unit of geometrical area (in order of multiple times compared to conventional capacitors). They are taking place in the area in-between lead batteries and conventional capacitors. In terms of specific energy (accumulated energy per mass unity or volume) and in terms of specific power (power per mass unity or volume) they take place in the area that covers the order of several magnitudes. Supercapacitors fulfill a very wide area between accumulator batteries and conventional capacitors taking into account specific energy and specific power [1]. Batteries and fuel cells are typical devices of small specific power, while conventional capacitors can have specific power higher than 1MW/dm^3, but at a very low specific energy. Electrochemical capacitors improve batteries characteristics considering specific power or improve capacitors characteristics considering specific energy in combination with them. In relation to other capacitor types, supercapacitors offer much higher capacitance and specific energies [5-6].

Accumulator batteries and low temperature fuel cells are typical devices with low specific power, where conventional capacitors may have specific power over 1MW/dm^3, but at very low specific energy. Electrochemical capacitor can improve characteristics of batteries in terms of specific power and improve properties of capacitors in terms of specific energy when they are combined with them [7].

The principal supercapacitor characteristic that makes it suitable for using in energy storage systems (ESS), is the possibility of fast charge and discharge without lost of efficiency, for thousands of cycles. This is because they store electrical energy directly. Supercapacitors can recharge in a very short time having a great facility to supply high and frequent power demand peaks [8].

2.3.1. Supercapacitor caracterization

Electrochemical investigation methods are widely used for characterization of different kinds of materials, as well as of the processes in systems where the electrochemical reactions take part. There is a series of well known methods, but some new methods from electrotechnical area have been introduced [9-10]. So, first of all it was given an overview of the standard electrochemical methods and parameters, beginning with potential measurement and simple methods such as chronopotentiometry and chronoamperometry, till electrochemical impedance spectroscopy [10]. The last named method is adapted for systems containing large capacitances that became actually with appearance of electrochemical supercapacitors. New methods are Dirac voltage excitation and Dirac current excitation. Measurement system described here allows application of electrochemical methods, as follows: measuring open circuit potential, chronopotentiometry, chronoamperometry, galvanostatic method, potentiostatic method, Dirac voltage excitation, galvanodynamic method, cyclic voltammetry and electrochemical impedance spectroscopy [10-11].

2.3.2. Supercapacitors as a function of increasing energy efficiency of EV

Most strict requirements are related to supercapacitors applying in electric haulage, i.e. for vehicles of the future. Nowadays, batteries of several hundred farad capacitance are with working voltage of several hundred volts have been produced. Beside great capacitance and relatively high working voltage, these capacitors must have great specific energy and power (because of limited space in vehicle). Considering their specific power, they have great advantage in relation to accumulator batteries, but, on the other side, they are incomparably weaker considering specific energy. Hence, ideal combination is parallel connection of accumulator and condenser batteries. In an established regime (normal drawing) vehicle engine is supplied from accu-battery, and in the case of rapidly speeding, from supercapacitor. Very important is the fact that in the case of abrupt breaking, complete mechanical energy could be taken back to system by converting into electrical energy only in presence of supercapacitor with great specific power [1].

In Figure 6 the scheme of an electrical drive vehicle in which supercapacitor is used for energy storage and so-called regenerative breaking is presented.

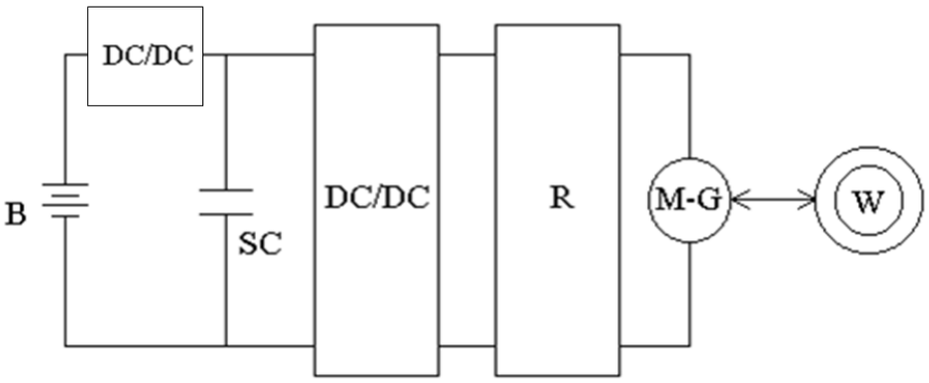


Figure 6. Scheme of electrical drive vehicle with supercapacitor with possibitlity for using breaking energy; B – one-way voltage source, SC – supercapacitor; DC/DC – direct voltage converter; R – regulator; M-G – engine – generator (depending on working regime; W – drive wheels

2.3.3. Supercapacitors in regulated electrical drives

Regulated electrical drives are more than 30% of all electric drives. They are developing quickly and present to constructors stricter and stricter speed regulation (and position) and torque. From energy point of view it is desirable their more participation, since optimal speed setting or required can lead to reduction of used energy [1].

DC source voltage is performed by means of DC-DC converter (chopper). Figure 7 shows principal scheme of such a system.

To provide breaking, or to dissipate braking energy that cannot be returned to the network through diode rectifier, it is required to have braking device with transistor T and resistor R.

Input voltage U_{do} is filtered by simple LC filter and brought to the chopper input that regulates mean value of output voltage U_d.

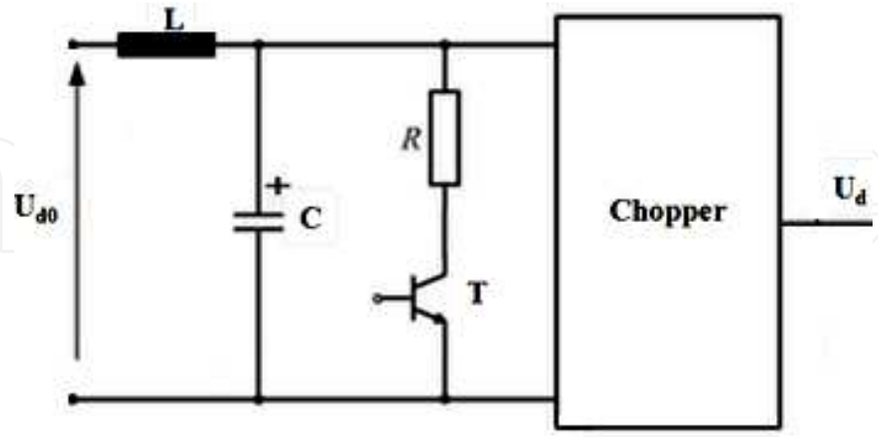


Figure 7. Principal scheme of chopper supply with supercapacitor

2.3.4. Accu batteries

Nowadays, there are a great amount of standard batteries that can be used for EV, however every single type has disadvantages that affect the performance of the vehicle. Therefore, compromises are often made between cost and quality, at the expense of energy efficiency almost all the time. Batteries in combination with supercapacitors are significant improvement and for now this is the system that has the best perspective for future EV.

In the table 1 it is presented the cost per Watt-hour and Specific Energy (Watt-hours per kilogram) for various types of batteries. It is not surprising that the well-known Lead-acid storage batteries head the list. Alkaline cells may be recharged literally dozens of times using the new technology. Recharging alkaline, nickel-cadmium and nickel-metal hydride cells side-by-side in one automatic charger opens up new possibilities for battery selection economy [12].

Battery type	Cost, USD/Wh	Specific Energy, Wh/kg
Lead-acid	0.17	41
Alkaline long-life	0.19	110
NiMH	0.99	95
NiCd	1.50	39
Lithium-ion	0.47	128

Table 1. Batteries cost per Watt-hour and Specific Energy

Costs of lithium-ion batteries are falling rapidly in the race to develop new electric vehicles. The $0.47 price per watt-hour above is for the Nissan Leaf automobile, and they predict a target

cost of $0.37 per watt-hour. Tesla Automobiles uses a smaller battery pack, and they are optimistic about reaching a price of $0.20 per watt-hour in the near future [12].

There is another type of battery that does not appear in the table above, since it is limited in the relative amount of current it can deliver. However, it has even higher energy storage per kilogram, and its temperature range is extreme, from -55 to +150°C. That type is Lithium Thionyl Chloride. It is used in extremely hazardous or critical applications. The specifications for Lithium Thionyl Chloride are $1.16 per watt-hour, 700 Watt-hours per kilogram [12].

Several parameters can be considered for selecting the more adequate battery typology: specific energy, specific power, cost, life, reliability, etc. In addition, it is to be considered that batteries for hybrid electric vehicles require higher powers and lower energies than batteries for pure electric vehicles. Among the previously listed typologies, Lead-acid and Nickel-Cadmium andSodium-Nickel Chloride batteries are normally used on board electric vehicles, because of their low specific powers [13].

2.3.5. Fuel cells

As far as the fuel cells are concerned, several types are available today, but for vehicle propulsion, Polymer Electrolyte Fuel Cell (PEFC) systems, fed by air and pure hydrogen stored aboard, seem to be highly preferable over other types, mainly because their reduced operating temperature (65-80 degrees depending on the cell design) allow very fast start-up times, and eases the thermal management. A Polymer Electrolyte Fuel Cell is an electrochemical device that converts chemical energy directly into electrical energy, without need of intermediate thermal cycles. It normally consumes H2 and O (typically from Air) as reactants and produce water, electricity and heat. Since cell voltage is so low (less than 1 V), several cells are normally connected in series to form a fuel cell stack with a voltage and power suitable for practical applications.

A fuel cell electric vehicle (FCEV) has higher efficiency and lower emissions compared with the internal combustion engine vehicles. But, the fuel cell has a slow dynamic response. Therefore, a secondary power source is needed during start up and transient conditions. Ultracapacitor can be used as secondary power source. By using ultracapacitor as the secondary power source of the FCEV, the performance and efficiency of the overall system can be improved. In this system, there is a boost converter, which steps up the fuel cell voltage, and a bidirectional DC-DC converter, that couples the ultracapacitor to the DC bus (fig. 8) [13-14].

2.3.6. New systems

The priority of the EV future development and its commercial success certainly is optimization of the electric power supply. Besides the usual combinations (batteries and supercapacitors, and supercapacitors), researches are going towards new systems that integrate favorable characteristics of the previously used systems.

Typically, standard ultracapacitors can store only about 5% as much energy as lithium-ion batteries. New hybrid system can store about twice as much as standard ultracapacitors, al-

though this is still much less than standard lithium-ion batteries. However, the advantage of ultracapacitors is that they can capture and release energy in seconds, providing a much faster recharge time compared with lithium-ion batteries. In addition, traditional lithium-ion batteries can be recharged only a few hundred times, which is much less than the 20,000 cycles provided by the hybrid system. In other words, the hybrid lithium-ion ultracapacitors have more power than lithium-ion batteries, but less energy storage. In the future, the hybrid lithium-ion ultracapacitor could also be used for regenerative braking in vehicles, especially if it could be scaled up to provide greater energy storage. Since vehicle braking systems need to be recharged hundreds of thousands of times, the hybrid system's cycle life will also need to be improved [15].

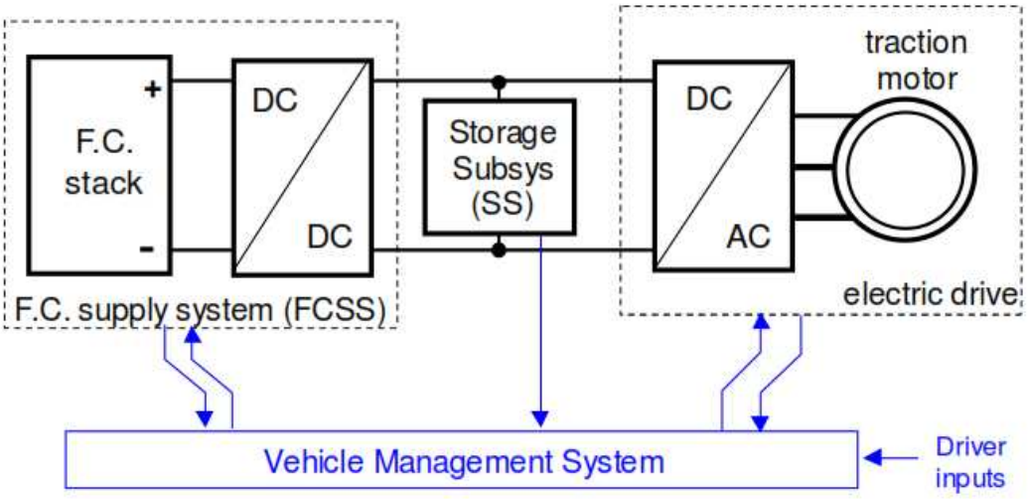


Figure 8. Vehicle with an electrochemical storage system

Using new processes central to nanotechnology, researchers create millions of identical nanostructures with shapes tailored to transport energy as electrons rapidly to and from very large surface areas where they are stored. Materials behave according to physical laws of nature. The Maryland researchers exploit unusual combinations of these behaviors (called self-assembly, self-limiting reaction, and self-alignment) to construct millions -- and ultimately billions -- of tiny, virtually identical nanostructures to receive, store, and deliver electrical energy [16].

2.4. Reduction of losses in the conductors and connectors

From the viewpoint of energy efficiency, choice of supply voltage, as well as quality contacts in the connectors and cable section is very important. The designer is limited by other factors such as the security problem (for battery overvoltage), limited space and cost. Therefore, it is necessary to optimize the supply voltage and the conductor section with given constraints. It is similar to the choice of connectors.

Hybrid and electric vehicles have a high voltage battery pack that consists of individual modules and cells organized in series and parallel. A cell is the smallest, packaged form a battery can take and is generally on the order of one to six volts. A module consists of several cells generally connected in either series or parallel. A battery pack is then assembled by connecting modules together, again either in series or parallel [17]. The pack operates at a nominal 375 volts, stores about 56 kilowatt hours (kWh) of electric energy and delivers up to 200 kilowatts of electric power. These power and energy capabilities of the pack make it essential that safety be considered a primary criterion in the pack's design and architecture [18].

Recent battery fires in electric vehicles have prompted automakers to recommend discharging lithium ion batteries following serious crashes. However, completely discharging a vehicle's battery to ensure safety will permanently damage the battery and render it worthless. Self-discharge effects and the parasitic load of battery management system electronics can also irreversibly drain a battery.

Zero-Volt technology relies on manipulating individual electrode potentials within a lithium ion cell to allow deep discharge without inflicting damage to the cell. Quallion has identified three key potentials affecting the Zero-Volt performance of lithium ion batteries. First, the Zero Crossing Potential (ZCP) is the potential of the negative electrode when the battery voltage is zero. Second, the Substrate Dissolution Potential (SDP) is the potential at which the negative electrode substrate begins to corrode. Finally, the Film Dissolution Potential (FDP) is the potential at which the SEI begins to decompose. The crucial design parameter is to configure the negative electrode potential to reach the ZCP before reaching either the SDP or the FDP at the end of discharge. This design prevents damage to the negative electrode which would result in permanent capacity loss. Figure 9 shows a schematic of the voltage profile during deep discharge of Quallion's Zero-Volt cells [18].

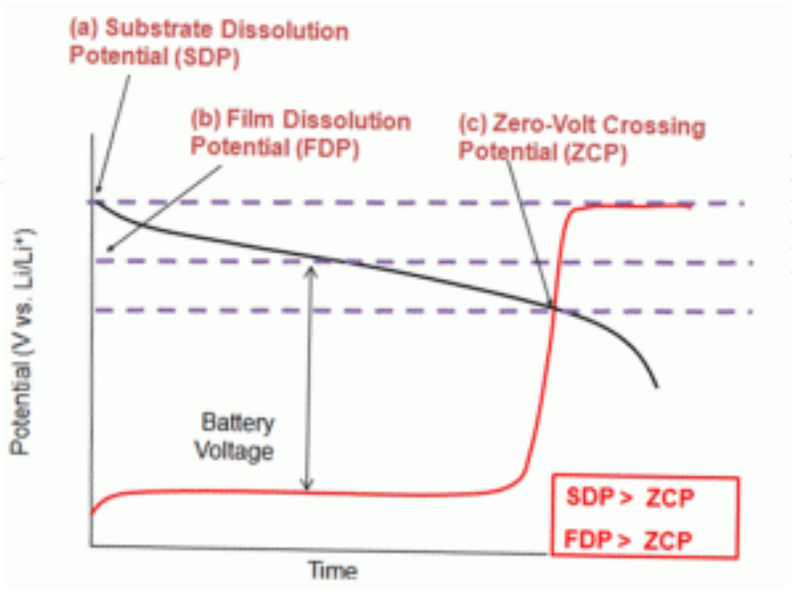


Figure 9. Schematic of key Zero-Volt potentials

Connector contacts are very important, both in terms of energy efficiency (when it comes to high power), and in terms of reliability and security. In recent years, the copper alloy with silver and / or gold is used, but other combinations of metals are to be explored [90.91]. So the compromise between good electrical and mechanical properties, on the one hand, and reasonable prices on the other is required.

Recent literature describes efforts devoted to investigation of copper based alloys in search of improvements in strength and maintenance of strength at high temperatures. The copper-silver alloy is an example of eutectic systems with the eutectic point at 779 ^{o}C when the alloy contains 72 % silver and 28 % copper. On both sides of the phase diagram there is a small solubility of the mentioned metals in each other. The maximum solubility of silver in copper is 4.9 at% and the slope of the solvus line indicates the possibility of age-hardening certain alloy compositions. Similar phenomenon - the strengthening of cold worked substitution solid solutions upon annealing up to the re-crystallization temperature is termed anneal hardening. The anneal hardening effect had been observed in Cu-Ag alloys in the annealing temperature range of 140-400 ^{o}C, the hardness being increased with the degree of preformation [4,5]. The goal of present work is to investigate corrosion behavior of this alloy obtained by fusion and cast (so called ingot metallurgy - IM) method in different stages of synthesis and thermomechanical treatment. Passivity of copper and its alloys is of interest with respect to basic and applied research due to its wide application in industry. Silver-copper alloys have been investigated elsewhere from the corrosion view point or as an electrode material, but the content of silver in all this alloys overcomes 15 % [19-22].

2.5. Lighting and heating of EV

With the rapid development of high intesive LED technology, it enabled large savings in energy consumption. That fact is crucial for EV. LED and power consumption of exterior vehicle lighting indicated that an all-LED system employing the current generation of LEDs would result in general power savings of about 50% (night time) to about 75% (daytime) over a traditional system. This means that while the long-term fuel cost savings (money) were higher for the gasoline-powered vehicle, long-term distance savings (range) favored the electric vehicle. Now, automotive lighting producer Osram comes to strengthen the idea mentioned above, stating that "micro-hybrids" or mild hybrids, which feature engine stop/start mechanisms to boost the efficiency of conventional vehicles, will benefit greatly from LED lighting by reducing power draw and battery drain, as well as increasing light output during low power mode and startups [23].

Today's roads have very little actual technology incorporated into their design and function. There are many types of technologies which could be incorporated, but we'll begin with what we say is the most important new feature which will soon be applied to actual roads. Since EVs are becoming increasingly popular, while their batteries are still much too weak to assure an anxiety-free drive on the highway, the induction charging (wireless) will begin to be incorporated into one of the lanes, so that these all-electric cars will be able to drive on the highway without using their on-board batteries at all, as they will get their juice straight from underneath the road surface (fig. 10). The idea of

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inductive charging is simple, and various companies and universities are testing the system now, in view of future mass implementation [23].

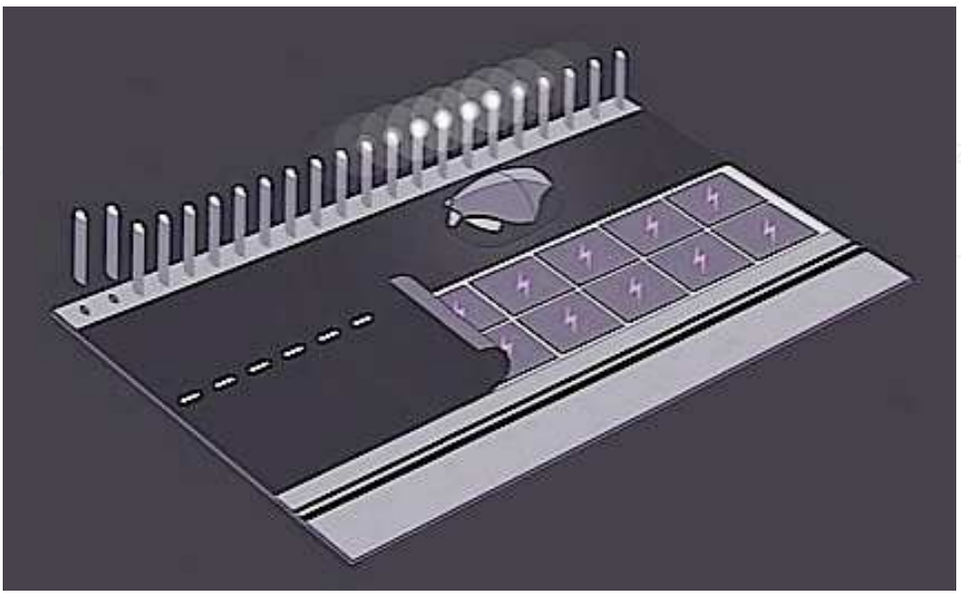


Figure 10. Road surface that charges batteries

Electric vehicles generate very little waste heat and resistance electric heat may have to be used to heat the interior of the vehicle if heat generated from battery charging/discharging can not be used to heat the interior. While heating can be simply provided with an electric resistance heater, higher efficiency and integral cooling can be obtained with a reversible heat pump (this is currently implemented in the hybrid Toyota Prius). Positive Temperature Coefficient (PTC) junction cooling [24] is also attractive for its simplicity — this kind of system is used for example in the Tesla Roadster.

Some electric cars, for example the Citroën Berlingo Electrique, use an auxiliary heating system (for example gasoline-fueled units manufactured by Webasto or Eberspächer) but sacrifice "green" and "Zero emissions" credentials. Cabin cooling can be augmented with solar power, most simply and effectively by inducting outside air to avoid extreme heat buildup when the vehicle is closed and parked in the sunlight (such cooling mechanisms are available as aftermarket kits for conventional vehicles). Two models of the 2010 Toyota Prius include this feature as an option [25].

3. Mechanical losses reduction in EV

3.1. Tyres role in EV

Large impact on the fuel consumption of the cars in general, has tires on its wheels. If the tire optimization is done by the energy efficiency criteria, with acceptable stability, comfort and

durability, there is a wide range for development and research. One of the fine examples of the intensive development in this field is racing cars. A modern racing car is a technical masterpiece, but considering the development effort invested in aerodynamics, composite construction and engines it is easy to forget that tyres are still a race car's biggest single performance variable. Average car with good tyres could do well, but it is very known fact that the one with bad tyres, even the very best car did not stand a chance. Despite some genuine technical crossover, race tyres and road tyres are - at best - distant cousins at the moment. An ordinary car tyre is made with heavy steel-belted radial plies and designed for durability - typically a life of 16,000 kilometers or more (10,000 miles). For example, a Formula One tyre is designed to last for, at most, 200 kilometers and it is constructed to be as light and strong as possible. That means an underlying nylon and polyester structure in a complicated weave pattern designed to withstand far larger forces than road car tyres, in [26].

The racing tyre itself is constructed from very soft rubber compounds which offer the best possible grip against the texture of the racetrack, but wear very quickly in the process. All racing tyres work best at relatively high temperatures. For example, the dry 'grooved' tyres used up until very recently were typically designed to function at between 90 degrees Celsius and 110 degrees Celsius [103]. However, electric vehicles can benefit from the years of research and usage of this kind of tyres. The development of the racing tyre came of age with the appearance of 'slick' tyres in the 1960s. Teams and tyre makers realized that, by omitting a tread pattern on dry weather tyres, the surface area of rubber in contact with the road could be maximized. This led to the familiar sight of 'grooved' tyres, the regulations specifying that all tyres had to have four continuous longitudinal grooves at least 2.5 mm deep and spaced 50mm apart. These changes created several new challenges for the tyre manufacturers - most notably ensuring the grooves' integrity, which in turn limited the softness of rubber compounds that could be used, in reference [26].

The 'softness' or 'hardness' of rubber compounds is varied for each road according to the known characteristics of the material that the road was made of. The actual softness of the tyre rubber is varied by changes in the proportions of ingredients added to the rubber, of which the three main ones are carbon, sulfur and oil. Generally speaking, the more oil in a tyre, the softer it will be. Formula One tyres are normally filled with a special, nitrogen-rich air mixture, designed to minimize variations in tyre pressure with temperature. The mixture also retains the pressure longer than normal air would, in [26].

The key characteristics of the new rubber - developed together with the teams in response to the latest aerodynamic regulations - are squarer profiles, increased grip, and softer, more competitive compounds with consistent degradation, optimizing the compounds and profiles to guarantee even better and more stable performance, a longer performance peak, combined with the deliberate degradation that characterized, in [27].

This new measure, which should result in a reduction of aerodynamic down force acting on each tyre, requires a wider and more even contact surface. This objective has been met by having a less rounded shoulder on each tyre and using softer compounds, which produce better grip and more extreme performance, in [27].

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Dry weather tyres, known as slicks, are characterized by a tread pattern that is devoid of blocks or channels. Wet weather tyres are characterized by grooves in the tread pattern. The full wet tyres can be easily recognized by the deep grooves in the tread pattern, in reference [28].

At this year's Geneva International Motor Show, one of the tyre manufacturers Goodyear unveils its latest innovation in tyre technology: an extremely low rolling resistance version of its award winning Goodyear EfficientGrip summer tyre with Fuel Saving Technology – specifically developed to fulfill the distinctive requirements of future electric vehicles, in [29]. The look of the tyre inside as well as of the tyre outside is presented in figure 11.



Figure 11. New Goodyear EfficientGrip summer tyre for EV.

The Goodyear EfficientGrip prototype tyre for electric vehicles delivers a range of benefits, including top rated energy efficiency and excellent noise and wet braking performance levels – in combination with Goodyear's latest generation of RunOnFlat Technology for continued mobility after a puncture or complete loss of tire pressure, in [29]. The design of the concept tyre is uniquely suited to complement the performance requirements of electric vehicles. The tyre's narrow shape in combination with its large diameter leads to reduced rolling resistance levels and to a reduced aerodynamic drag and thus reduced energy consumption.

Rolling resistance is mainly caused by the energy loss due to the deformation of the tyre during driving. Less deformation means less energy loss and hence, less rolling resistance. Goodyear engineers used the latest computer simulation technologies to analyze the tyre's potential deformation behavior during driving. The larger rim diameter reduces the overall amount of rubber that is needed, which leads to less rubber deformation during driving. The large tyre diameter requires fewer tire rotations for a certain distance, which in turn results in less heat buildup and tire deformation, which again leads to lower rolling resistance levels and less energy consumption, in [29].

Electric engines often provide a relatively constant torque, even at very low speeds, which increases the acceleration performance of an electric vehicle in comparison to a vehicle with a similar internal combustion engine. This required the development of a modified tread design in combination with a new tread compound to ensure excellent grip especially on dry, and to provide high levels of mileage, in [29].

This EfficientGrip concept tyre showcases our enormous research and development efforts to support the development of electric vehicles with tyres that provide extremely low rolling resistance and noise levels in combination with a very high level of wet performance. Fitted on a standard car this tyre would give 30 percent less rolling resistance which leads to about 6 percent less fuel consumption compared to an average standard summer tyre, in [29].

The effect of tyre pressure on either fuel consumption with regular cars or EV consumption is emphasized. Some researches were done in USA in the last few years. For the control test, the pressure was set at the factory recommended 33 psi in each tire. The subsequent test was done with the pressure set at 45 psi. For each test, the vehicle was driven a total of 550 miles over the course of one week travelling back and forth between the same two cities via the same route. The fuel tank was filled twice per week. Measurement of the quantity of fuel used was taken from the readout on a gas pump at each fill-up. The number of miles travelled was taken from the vehicle's trip odometer, in [190]. Results showed that during the control period, the number of miles travelled per gallon of gasoline consumed was 27. With the tire pressure at 45 psi, the vehicle travelled 30 miles per gallon of gasoline consumed; a difference of 11 percent, in [30].

3.2. Vehicle body

Automotive design and, specifically, the design of electric and hybrid-electric vehicles, involve a variety of challenges that have to be considered by an appropriate design environment. The convergence of more and more electronics with controls and mechanics makes the design process very complex and involves a variety of technical disciplines. With the complex interactions between the individual system parts, a disconnected consideration of each individual domain is not sufficient anymore. Each individual domain requires specific algorithms and modeling languages to achieve optimal performance for the analysis of that specific domain. A single algorithm usually does not perform for all domains equally; therefore the combination of different algorithms via co-simulation expands the design capabilities of the system considerably (Fig. 12) [31].

In recent years simulation programs allow the optimization of vehicle body shapes from the standpoint of energy efficiency. On the other hand, simulations and experiments in the wind tunnel achieve significant energy savings by introducing air turbine, which inevitably airflow into electricity.

3.3. Aerodynamics of EV

Moveable aerodynamic components are nothing new, every time you sit on an airliner you see the wing flaps, ailerons moving around, and often as you come into land you can see the

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array of hydraulics employed to move them. The systems on a Formula 1 racing car work in essentially the same way. Hydraulic tubes, rods and actuators. But whilst on an Airbus A320 or even a modern UAV or fighter jet there is a huge amount of space to work in, on a grand prix car the opposite is true [32]. EV vehicles could benefit a lot from these technologies.

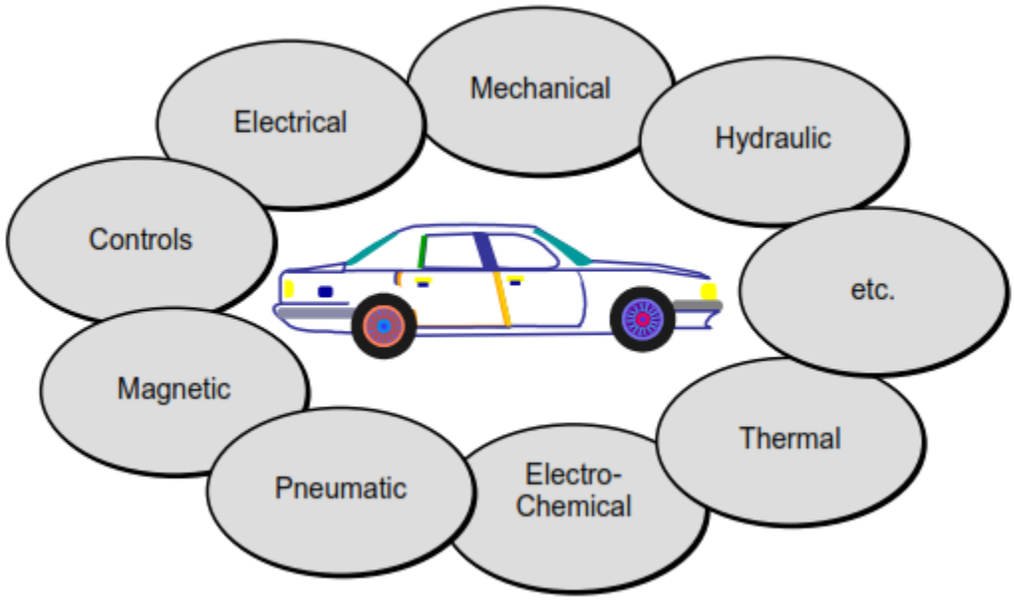


Figure 12. Multi-Domain Design

Racing drivers have a new tool at their disposal, called Drag Reduction System (DRS). It is essentially an adjustable rear wing which can be used to facilitate overtaking. The flap is lifted up at the front and pivots about a point at the trailing edge of the wing, so that in the event of a failure, the flap will drop down into the default, high-down force position. Since the timing loops will be sited after corners, drivers will only be able to deploy the active rear wing as a car goes down a particular nominated straight [32].

The materials used in these systems also require great precision. Today in F1 it is mainly titanium tube, though some of what we do involves peek mainly in the fuel system but primarily titanium. Aluminum and stainless steel are also used. Titanium is favored for its inherent lightness and strength, and it means that it is possible to make the cross section of the material so much thinner than if you were using Aluminum. Over the time, the manufacturers have learned to manipulate titanium tubing in ways, especially in small spaces, and the results of that work will be on cars in the future [32].

This week a row has erupted over the design of two teams' diffusers, after the new Williams and Toyota emerged sporting radically different diffuser designs to the other cars launched so far. Williams came up with a 'double decker' diffuser design, while Toyota initially tested an extension to the middle of their diffuser, and then later added a double decker section of their own. Both these designs raised eyebrows up and down the pit lane, as they appear to stretch the wording of the new rules. [33].

As part of the 2009 package of aerodynamic rule changes designed to reduce down force and increase overtaking, the FIA mandated a smaller diffuser in a more rearward position. With the shock of losing 50 per cent of their down force because of these changes, teams have been working hard to get the bodywork shaped to the new rules to regain the lost down force [33].

4. Additional energy in EV

4.1. Solar cells

Today, world recognizes the synergy between solar panels and electric cars. As the matter a fact there are several car companies that plan to install solar panels in their newer hybrid vehicles. The most important question for most of these manufacturers is: how much extra power will a solar roof panel actually provide? It's very difficult to generate enough power to move a vehicle with energy from the sun's light. So, solar panels at the moment don't have that much of an impact on a hybrid and electric car's efficiency. Solar panels are also made out of silicon, which is too expensive for automakers to use as a viable source [34].

However, there are companies such as Toyota, one of the pioneers in this field, which uses the solar roof panel. Constant technology development will provide better conditions in years that follow for this option. Nowadays, roof panel will power at least part of the hybrid Toyota Prius' air-conditioning unit. Smaller, less power-hungry systems seem to work better with solar power [34].

The most common type of solar panel uses single- or multi-crystalline silicon wafers. Creating the silicon crystal is by far the most energy intensive part of the process, followed by various and sundry manufacturing steps, such as cutting the silicon into wafers, turning the wafers into cells and assembling the cells into modules [35].

The today's electric vehicles consume about 150 watt-hours per kilometer. If the average distance per day is 50 km, then it would be 18,250 kilometers per year. For this calculated consumption, electric vehicle would need to generate 2.75 MWh/year. By this math, mono-crystalline solar panels generate about 263 kWh/m^2 per year in the USA. Therefore, about 10.5 square meters of solar panels to completely offset the energy consumed by today's electric vehicles [35]. The only practical place to put panels on the Roadster is the roof (about 1 square meter). Ideally, this would then generate 263 kWh/year. However, the Roadster won't always be in the sun, and it won't be at its ideal angle. A 60% de-rating would be generous to account for shade and suboptimal angles, so the panel would generate about 150 kWh/year – driving the car an additional 3 kilometers per day [35].

However, there is possibility to put solar cells on the other part of the vehicle's surface. The surface from the vehicle's nose, across the hoods, and all the way to the roof can be used for solar cells as presented in figure 13. Also, technology development will without a doubt make progress in increasing solar energy efficiency.

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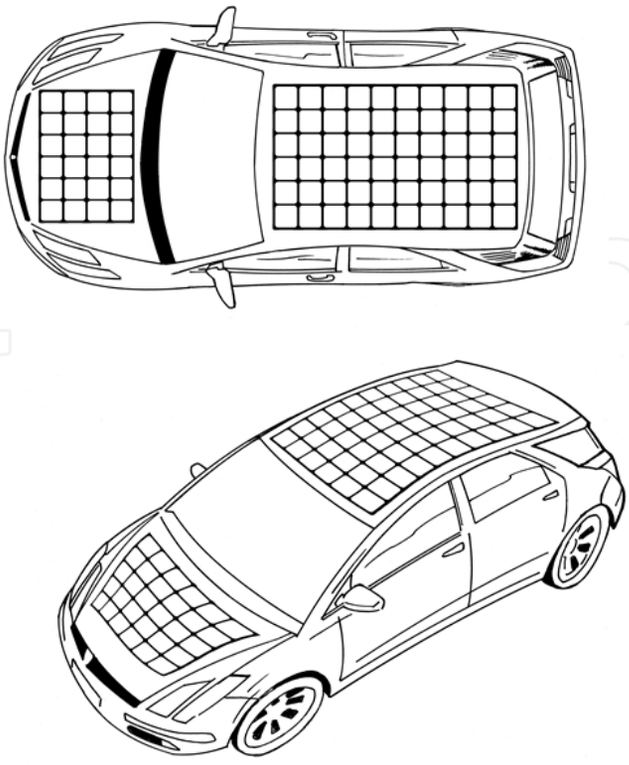


Figure 13. Position of solar cells on the surface of the electric vehicle

4.2. Energy recovery systems

4.2.1. Kinetic energy recovery systems

A kinetic energy recovery system (KERS) is an automotive system for recovering a moving vehicle's kinetic energy under braking. The recovered energy is stored in a reservoir (flywheel or a battery or/and supercapacitor) for later use under acceleration. The device recovers the kinetic energy that is present in the waste heat created by the car's braking process. It stores that energy and converts it into power that can be called upon to boost acceleration, in [36].

The concept of transferring the vehicle's kinetic energy using flywheel energy storage was postulated by physicist Richard Feynman in the 1950s. It is exemplified in complex high end systems such as the Zytek, Flybrid, Torotrak and Xtrac used in F1 and simple, easily manufactured and integrated differential based systems such as the Cambridge Passenger/Commercial Vehicle Kinetic Energy Recovery System (CPC-KERS), in [36].

Xtrac and Flybrid are both licensees of Torotrak's technologies, which employ a small and sophisticated ancillary gearbox incorporating a continously variable transmission (CVT). The CPC-KERS is similar as it also forms part of the driveline assembly. However, the whole mechanism including the flywheel sits entirely in the vehicle's hub (looking like a drum brake). In the CPC-KERS, a differential replaces the CVT and transfers torque between the flywheel,

drive wheel and road wheel [36]. KERS Technology is based on a completely new design capable of accumulating power and keeping it in store for the right moment.

KERS Technology works like a turbo charger that provides additional power and acceleration by stiffening the tail of the ski in outturns. The effect: a boost, catapulting the rider into the next turn. Just like when Formula 1 pilots push a button for that extra notch of speed. KERS Technology is an electronic, fully automatic and integrated system. Piezoelectric fibers transform kinetic energy into electrical energy which is stored. Electrical energy is immediately released to areas of the ski, where additional energy is requested. Timing and release are automatically controlled and coordinated. Depending on the flex pattern of different ski models, sensors are programmed beforehand: the more aggressive the ski has to be, the stiffer the tail will become, in reference [37].

The key system features were:

- A flywheel made of steel and carbon fibre that rotated at over 60,000 RPM inside an evacuated chamber
- The flywheel casing featured containment to avoid the escape of any debris in the unlikely event of a flywheel failure
- The flywheel was connected to the transmission of the car on the output side of the gearbox via several fixed ratios, a clutch and the CVT
- 60 kW power transmission in either storage or recovery
- 400 kJ of usable storage (after accounting for internal losses)
- A total system weight of 25 kg
- A total packaging volume of 13 litres, in reference [38]

There are principally two types of system - battery (electrical) and flywheel (mechanical). Electrical systems use a motor-generator incorporated in the car's transmission which converts mechanical energy into electrical energy and vice versa. Once the energy has been harnessed, it is stored in a battery and released when required. Mechanical systems capture braking energy and use it to turn a small flywheel which can spin at up to 80,000 rpm. When extra power is required, the flywheel is connected to the car's rear wheels. In contrast to an electrical KERS, the mechanical energy doesn't change state and is therefore more efficient. There is one other option available - hydraulic KERS, where braking energy is used to accumulate hydraulic pressure which is then sent to the wheels when required, in [36,39].

The first of these systems to be revealed was the Flybrid. This system weighs 24 kg and has an energy capacity of 400 kJ after allowing for internal losses. A maximum power boost of 60 kW (81.6 PS, 80.4 HP) for 6.67 seconds is available. The 240 mm diameter flywheel weighs 5.0 kg and revolves at up to 64,500 rpm. Maximum torque at the flywheel is 18 Nm, and the torque at the gearbox connection is correspondingly higher for the change in speed. The system occupies a volume of 13 liters, in [36].

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Nowadays, Formula One has stated that they support responsible solutions to the world's environmental challenges and the FIA allowed the use of 60 kW KERS in the regulations for the 2009 Formula One seasone. Teams began testing systems in 2008: energy can either be stored as mechanical energy (as in a flywheel) or as electrical energy (as in a battery or supercapacitors). As of 2014, in the race cars, the power capacity of the KERS units will increase from 60 kilowatts to 120 kilowatts, in [106].

The aims for introducing KERS technology in the racing world are twofold. Firstly to promote the development of environmentally friendly and road car-relevant technologies in Formula One racing; and secondly to aid overtaking. A chasing driver can use his boost button to help him pass the car in front, while the leading driver can use his boost button to escape. A typical KERS system weighs from 25 to 35 kilograms, in [36,37,39]. For the relevance of the electric vehicles, this energy can be used for supplementing the batteries of electrical engine and thereby adding a few more kilometres to the driving distance at once.

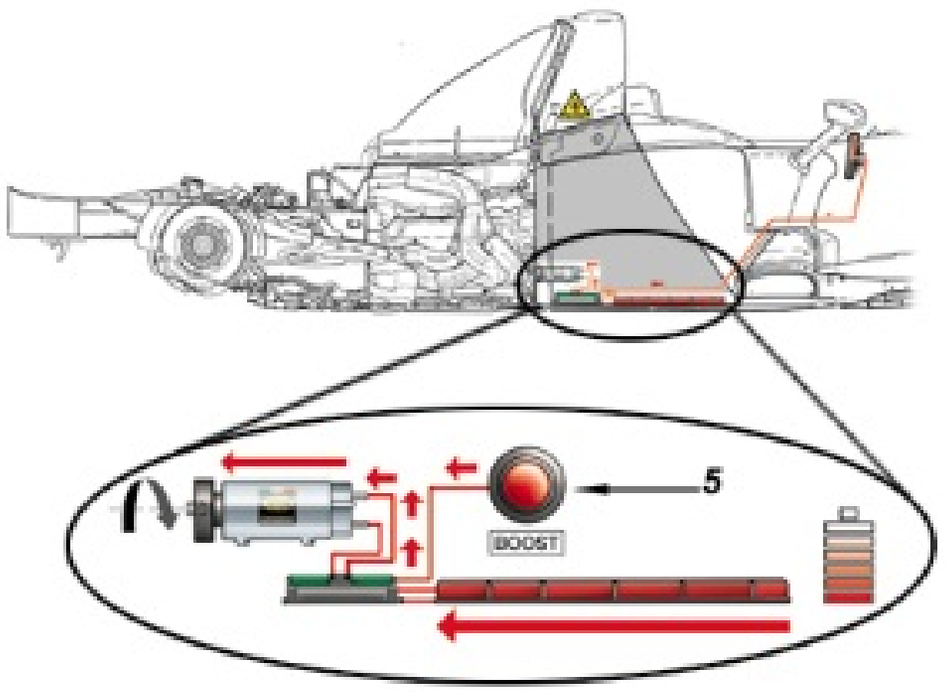


Figure 14. Kinetic Energy Recovery System

Following the current situation, some solutions in KERS packaging has taken a step forwards. Now the energy storage appears to be slightly revised, with the unit inside the gearbox swapped for floor mounted units. The two carbon fiber cases are closed with aluminum tops and are provided with electrical and cooling connections. They sit in the final section of flat floor known as the boat tail, in [40].

Having the units placed on the floor, as opposed to between the gearbox and engine, means they can lower the Centre of Gravity. Also being quite heavy they are placed near the rear axle line to suit the mandatory weight distribution. As mentioned the units are supplied with a

common cooling circuit, one pipe routes around the back of the floor to link the devices. There are also a number of electrical connections for both connecting to the KERS Power Control Unit and for monitoring their status. Quickly detachable connectors are used to allow rapid removal of the floor keeping the units in place, in [40].

The future development appear to have found a new mounting position and format for their KERS energy storage with what appear to be floor mounted super capacitors. Super Capacitors (supercaps) are alternative energy storage to Lithium Ion batteries, using very much the same technology as smaller capacitors used in electronics, in [40].

Typically current F1 cars use dozens of Li-ion cells packed into an array forming a 'battery' pack. This KERS Battery Pack is commonly a single part sat under the fuel tank. Although often used as a single battery, the unit can be broken up into a set of batteries in series. In 2011 Red Bull clearly split this part up into several smaller Battery Packs, there being the two aforementioned units either of the gearbox and another in the gearbox. Although interconnecting these parts with cooling pipes, high current cable and sensor cabling ads some weight, this does provide a nicer packaging solution. It's logical to explain these new floor mounted parts as batteries. However they do not look like the battery packs seen in the gearbox last year, or on other cars. Being on the floor of the car they are subject to even more danger from impacts as well as the heat and vibration that caused issues last year, in [40]. The energy stored in a double-layer capacitor, is used to supply power needed by vehicle electrical systems, in [36].

4.2.2. Waste heat energy recovery

In recent years, there has been active research on exhaust gas waste heat energy recovery for automobiles. Meanwhile, the use of solar energy is also proposed to promote on-board renewable energy and hence to improve their fuel economy. New research in thermoelectric-photovoltaic hybrid energy systems are proposed and implemented for automobiles. The key is to newly develop the power conditioning circuit using maximum power point tracking so that the output power of the proposed hybrid energy system can be maximized. This experimental concept can be easily implemented in electric vehicles [41].

According to the recent studies, General Motors is using shape memory alloys that require as little as a 10°C temperature difference to convert low-grade waste heat into mechanical energy. When a stretched wire made of shape memory alloy is heated, it shrinks back to its pre-stretched length. When the wire cools back down, it becomes more pliable and can revert to its original stretched shape. This expansion and contraction can be used directly as mechanical energy output or used to drive an electric generator. Shape memory alloy heat engines have been around for decades, but the few devices that engineers have built were too complex, required fluid baths, and had insufficient cycle life for practical use. Around 60% of all energy in the U.S. is lost as waste heat; 90% of this waste heat is at temperatures less than 200°C and termed low grade because of the inability of most heat-recovery technologies to operate effectively in this range. The capture of low-grade waste heat, which turns excess thermal energy into useable energy, has the potential to provide consumers with enormous energy savings [42].

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For practical use, parts of automotive industry nowadays are working to create a prototype that is practical for commercial applications and capable of operating with either air or fluid based heat sources. GM's shape memory alloy based heat engine is also designed for use in a variety of non-vehicle applications. For example, it can be used to harvest non-vehicle heat sources, such as domestic and industrial waste heat and natural geothermal heat, and in HVAC systems and generators [43].

Thermal Energy Recovery Systems for better fuel efficiency proposes solutions for fuel economy and lower CO2-emissions on combustion engines by making use of their exhaust waste heat. This fuel economy is accessible for engines running on gasoline, diesel, bio fuels, hydrogen or any other type of fuel. This solution proposes high power density for mobile applications and rugged solutions for power generation and marine applications, also being recognized by the motorsport world as an important technology for the future in racing and finally a technology that will contribute to the development of electric vehicle [43].

Plug-in hybrid electric vehicles are already noted for their environmental advantages and fuel savings – but now a new breakthrough technology could mean their fuel economy is boosted by a further seven per cent [44]. Most vehicle waste heat recovery systems that are currently being developed utilize a thermoelectric converter to create electricity, as the name implies, directly from heat. These devices depend on a unique property of certain materials which result in the Seeback effect, discovered in 1821, where the application of heat produces an electric current. The devices have no moving parts. You could think of them as similar to photovoltaic cells, except that they respond to heat rather than light [45].

An effective waste recovery system requires three elements:

1. a thermoelectric material package
2. an electric power management system, which directs the electricity injected into the vehicle's electrical system to the place where it will do the most good at any given time
3. a thermal management system, which is essentially a sophisticated heat exchanger [45]

Some other systems in hybrid electric vehicles reduce fuel consumption by replacing a significant portion of the required electric power normally produced by the alternator with electric power produced from exhaust gas waste heat conversion to electricity in a Thermo-electric Generator Module [46].

4.3. Airflow

It was previously mentioned that vehicle body can be designed to reduce downforce and otherwise adverse airflow. Some of the possibilities are presented here.

During forward motion of an electrically-powered vehicle, air is captured at the front of the vehicle and channeled to one or more turbines. The air from the turbines is discharged at low pressure regions on the sides and/or rear of the vehicle. The motive power of the air rotates the turbines, which are rotatable engaged with a generator to produce electrical energy that is used to recharge batteries that power the vehicle. The generator is rotatable engaged with a

flywheel for storing mechanical energy while the vehicle is in forward motion. When the vehicle slows or stops, the flywheel releases its stored energy to the generators, thereby enabling the generator to continue recharging the batteries. The flywheel enables the generators to provide a more stable and continuous current flow for recharging the batteries [47].

It is assumed that the vehicle is moving in a calm and steady wind stream with zero wind velocity. If the vehicle is moving at a constant speed of 15 m/s (54 km/h), then we can think a wind stream with15 m/s is flowing around the vehicle. Normally this wind will cause a drag force which is opposite to the direction of the propulsion of the vehicle. At constant speed (zero acceleration) the energy requirements to move the vehicle forward are –To overcome the frictional force (rolling resistance of road) and to overcome wind resistance [48]. At this Condition, if the air stream flowing around the vehicle (which was not interacting with the vehicle previously) is allowed to enter inside and let it flow down to the rear side; then it may be possible to use these air streams to generate power. The vehicle has already interacted with this wind and it d eflects the stream of wind at the two sides of it by stagnation at the front.

This is the energy that had been lost from the vehicle to overcome the aerodynamic resistant. Now if these stream generated by the interaction of the wind and vehicle is captured within the vehicle in such a way that it would not impose an additional drag at the direction of propulsion of the vehicle, some of the energy can be recovered and fed back to the battery by means of conventional energy conversion processes. Placing a wind turbine can serve the purpose. At the same time it will help to increase the pressure at the back side (according to Bernoulli's equation pressure will be increased if velocity is decreased and velocity will be reduced at the back side of the turbine after energy extraction) which will reduce the drag force that existed before with the conventional design of the vehicle. So, vortex shedding will be reduced at the rear side. For this it is necessary to modify the design of a vehicle which gives provision of air flow through the vehicle. On the other hand positioning of the turbines will also be important because they must be placed in such a way that they do not impose or create any additional drag on the vehicle. Symmetrical positioning of the turbine can do t he trick as the thrust acting on the turbines will cancel each other (Fig. 15) [49].

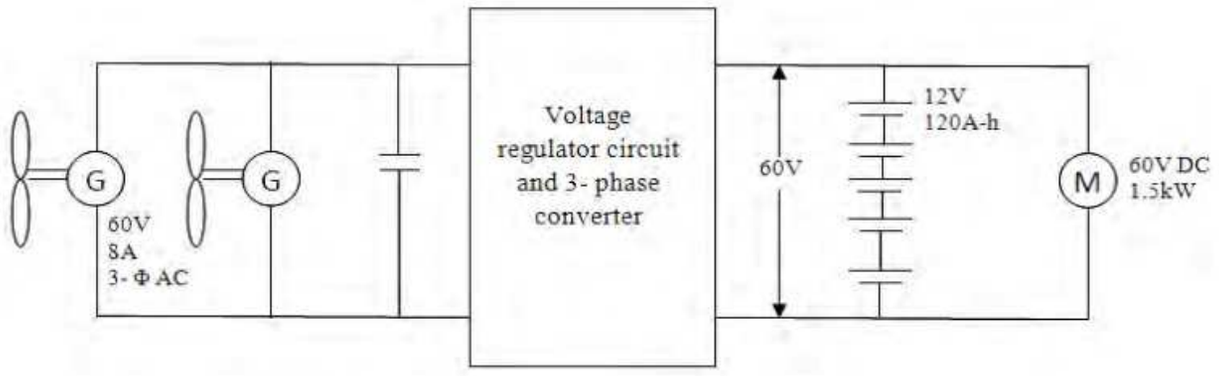


Figure 15. Charging and control circuit of the battery

4.4. Hybrid electric vehicle

Generally, hybrid vehicles could be described as vehicles using combination of technologies for energy production and storage. Two types of the vehicles are in consideration – so called parallel and linear hybrids. Parallel type possesses mechanical connection between power generator and drive wheels, while in linear one such connection does not exist. Serial hybrids have significant advantages in relation to parallel ones because of their mechanical simplicity, design flexibility and possibility for simple incorporation of new technologies [1].

Hybrid electric vehicles (HEVs) combine the internal combustion engine of a conventional vehicle with the high-voltage battery and electric motor of an electric vehicle. As a result, HEVs can achieve twice the fuel economy of conventional vehicles (Fig. 1). In combination, these attributes offer consumers the extended range and rapid refueling they expect from a conventional vehicle, as well as much of the energy and environmental benefits of an electric vehicle. HEVs are inherently flexible, so they can be used in a wide range of applications — from personal transportation to commercial hauling. Hybrid electric vehicles have several advantages over conventional vehicles:

- Greater operating efficiency because HEVs use regenerative braking, which helps to minimize energy loss and recover the energy used to slow down or stop a vehicle;
- Lighter engines because HEV engines can be sized to accommodate average load, not peak load, which reduces the engine's weight;
- Greater fuel efficiency because hybrids consume significantly less fuel than vehicles powered by gasoline alone;
- Cleaner operation because HEVs can run on alternative fuels (which have lower emissions), thereby decreasing our dependency on fossil fuels (which helps ensure our national security); and
- Lighter vehicle weight overall because special lightweight materials are used in their manufacture.

Hybrid electric vehicles are becoming cost-competitive with similar conventional vehicles, and most of the cost premium can be offset by overall fuel savings and tax incentives. Some states even offer incentives to consumers buying HEVs [50].

4.5. Today's high-speed EV

Nowadays, the most powerful high-performance electric vehicle has four electric motors producing a total output of 552 kW and a maximum torque of 1000 Nm. As a result, the gullwing model has become the world's fastest electrically-powered series production vehicle accelerates from zero to 100 km/h in 3.9 seconds [51].

Enormous thrust comes courtesy of four synchronous electric motors providing a combined maximum output of 552 kW and maximum torque of 1000 Nm. The very special gullwing model accelerates from zero to 100 km/h in 3.9 seconds, and can reach a top speed of 250 km/h (electronically limited). The agile response to accelerator pedal input

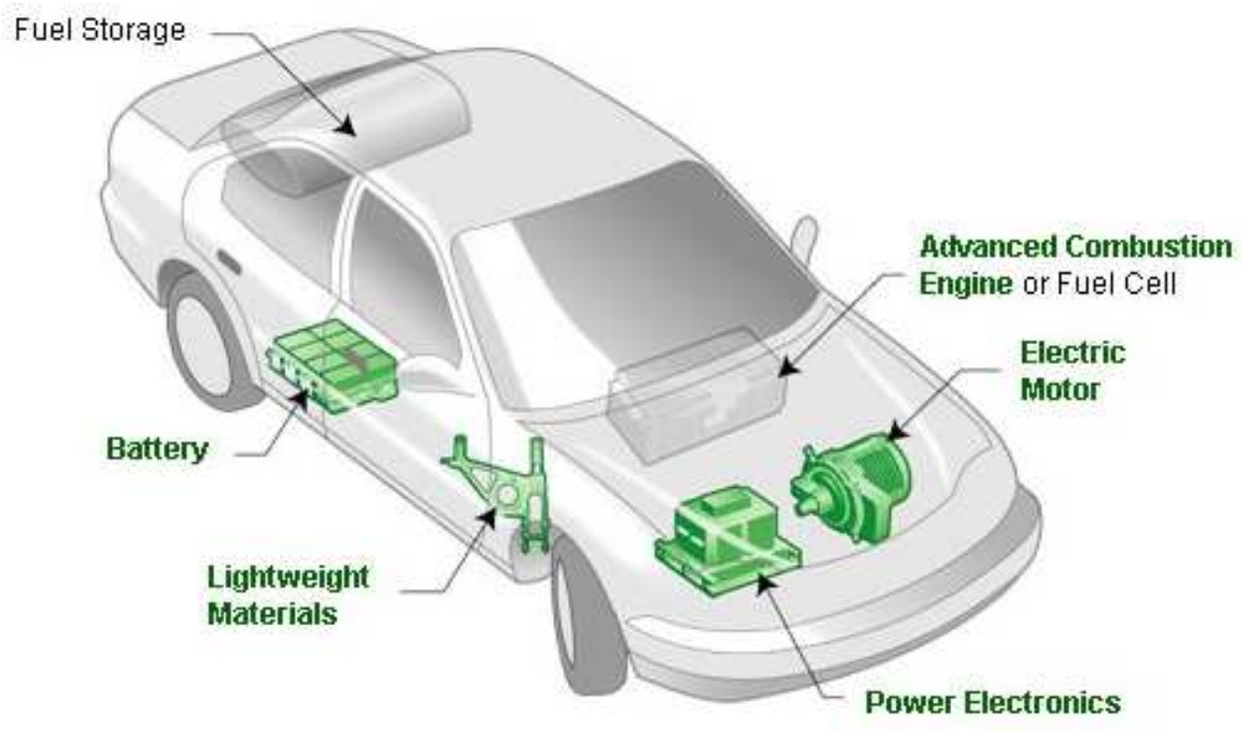


Figure 16. HEV

and the linear power output provide pure excitement: unlike with a combustion engine, the build-up of torque is instantaneous with electric motors – maximum torque is effectively available from a standstill. The spontaneous build-up of torque and the forceful power delivery without any interruption of tractive power are combined with completely vibration-free engine running characteristics [51].

The four compact permanent-magnet synchronous electric motors, each weighing 45 kg, achieve a maximum individual speed of 13,000 rpm and in each case drive the 4 wheels selectively via a axially-arranged transmission design. This enables the unique distribution of torque to individual wheels, which would normally only be possible with wheel hub motors which have the disadvantage of generating considerable unsprung masses [51].

Battery efficiency, performance and weight are by far the most important factors in electric vehicles. The high-voltage battery in the current high-performance electric vehicles boasts an energy content of 60 kWh, an electric load potential of 600 kW and weighs 548 kg – all of which are absolute best values in the automotive sector. The liquid-cooled lithium-ion high-voltage battery features a modular design and a maximum voltage of 400 V. Advanced technology and know-how from the world of Formula 1 have been called on during both the development and production stages [51].

The high-voltage battery consists of 12 modules each comprising 72 lithium-ion cells. This optimized arrangement of a total of 864 cells has benefits not only in terms of best use of the installation space, but also in terms of performance. One technical feature is the intelligent

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parallel circuit of the individual battery modules – this helps to maximize the safety, reliability and service life of the battery. As in Formula 1, the battery is charged by means of targeted recuperation during deceleration whilst the car is being driven [51].

A high-performance electronic control system converts the direct current from the high-voltage battery into the three-phase alternating current which is required for the synchronous motors and regulates the energy flow for all operating conditions. Two low-temperature cooling circuits ensure that the four electric motors and the power electronics are maintained at an even operating temperature. A separate low-temperature circuit is responsible for cooling the high-voltage lithium-ion battery. In low external temperatures, the battery is quickly brought up to optimum operating temperature with the aid of an electric heating element. In extremely high external temperatures, the cooling circuit for the battery can be additionally boosted with the aid of the air conditioning. This also helps to preserve the overall service life of the battery system [51].

Ideally the EV is charged with the aid of wall box. As it could be installed in a home garage, this technology provides a 22 kW quick-charge function, which is the same as the charging performance available at a public charging station. A high-voltage power cable is used to connect the vehicle to the wall box, and enables charging to take place in around three hours. Charging takes around 20 hours without the wall box [51].

To ensure maximum safety, the SLS AMG Coupé Electric Drive, one of the most advanced high-performance EV today, makes use of an eight-stage safety design. This comprises the following features:

- All high-voltage cables are color-coded in orange to prevent confusion
- Comprehensive contact protection for the entire high-voltage system
- The lithium-ion battery is liquid-cooled and accommodated in high-strength aluminium housing within the carbon-fibre zero-intrusion cell
- Conductive separation of the high-voltage and low-voltage networks within the vehicle and integration of an interlock switch
- Active and passive discharging of the high-voltage system when the ignition is switched to "off"
- In the event of an accident, the high-voltage system is switched off within fractions of a second
- Continuous monitoring of the high-voltage system for short circuits with potential compensation and insulation monitors
- Redundant monitoring function for the all-wheel drive system with torque control for individual wheels, via several control units using a variety of software

By using this design, EV manufacturers ensures maximum safety during production of the vehicle and also during maintenance and repair work [51].

The intelligent and permanent all-wheel drive concept, with four motors for four wheels guarantees driving dynamics at the highest level, while at the same time providing the best possible active safety. Optimum traction of the four driven wheels is therefore ensured, whatever the weather conditions. According to the developers, the term "Torque Dynamics" refers to individual control of the electric motors, something which enables completely new levels of freedom to be achieved. The AMG Torque Dynamics feature is permanently active and allows for selective distribution of forces for each individual wheel. The intelligent distribution of drive torque greatly benefits driving dynamics, handling, driving safety and ride comfort. Each individual wheel can be both electrically driven and electrically braked, depending on the driving conditions, thus helping to:

- optimize the vehicle's cornering properties
- reduce the tendency to over steer/under steer
- increase the yaw damping of the basic vehicle
- reduce the steering effort and steering angle required
- increase traction

AMG Torque Dynamics system enables optimum use of the adhesion potential between the tires and the road surface in all driving conditions. The technology allows maximum levels of freedom and as such optimum use of the critical limits of the vehicle's driving dynamics [51].

The trailblazing body shell structure of the SLS AMG Coupé Electric Drive is part of the ambitious "AMG Lightweight Performance" design strategy. The battery is located within a carbon-fiber monocoque which forms an integral part of the gullwing model and acts as its "spine". The monocoque housing is firmly bolted and bonded to the aluminum space frame body. The fiber composite materials have their roots in the world of Formula 1, among other areas. The advantages of CFRP (carbon-fiber reinforced plastic) were exploited by the Mercedes-AMG engineers in the design of the monocoque. These include their high strength, which makes it possible to create extremely rigid structures in terms of torsion and bending, excellent crash performance and low weight. Carbon-fiber components are up to 50 percent lighter than comparable steel ones, yet retain the same level of stability. Compared with aluminum, the weight saving is still around 30 percent, while the material is considerably thinner. The weight advantages achieved through the carbon-fiber battery monocoque are reflected in the agility of the electric vehicle and, in conjunction with the wheel-selective four-wheel drive system, ensure true driving enjoyment. The carbon-fiber battery monocoque is, in addition, conceived as a "zero intrusion cell" in order to meet the very highest expectations in terms of crash safety. It protects the battery modules inside the vehicle from deformation or damage in the event of a crash [51].

The basis for CFRP construction is provided by fine carbon fibers, ten times thinner than a human hair. A length of this innovative fiber reaching from here to the moon would weigh a mere 25 grams. Between 1000 and 24,000 of these fibers are used to form individual strands [51].

The purely electric drive system was factored into the equation as early as the concept phase when the super sports car was being developed. It is ideally packaged for the integration of

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the high-performance, zero-emission technology: by way of example, the four electric motors and the two transmissions can be positioned as close to the four wheels as possible and very low down in the vehicle. The same applies to the modular high-voltage battery. Advantages of this solution include the vehicle's low center of gravity and balanced weight distribution – ideal conditions for optimum handling, which the electrically-powered gullwing model shares with its petrol-driven sister model. Another distinguishing feature is the speed-sensitive power steering with rack-and-pinion steering gear: the power assistance is implemented electro hydraulically rather than just hydraulically [51].

The high-performance ceramic composite brakes are used in the latest electrical vehicles, which boast direct brake response, a precise actuation point and outstanding fade resistance, even in extreme operating conditions. The over-sized discs – measuring 402 x 39 mm at the front and 360 x 32 mm at the rear – are made of carbon fiber-strengthened ceramic, feature an integral design all round and are connected to an aluminum bowl in a radially floating arrangement. The ceramic brake discs are 40 percent lighter in weight than the conventional, grey cast iron brake discs. The reduction in unsprung masses not only improves handling dynamics and agility, but also rides comfort and tire grip. The lower rotating masses at the front axle also ensure a more direct steering response – which is particularly noticeable when taking motorway bends at high speed [51].

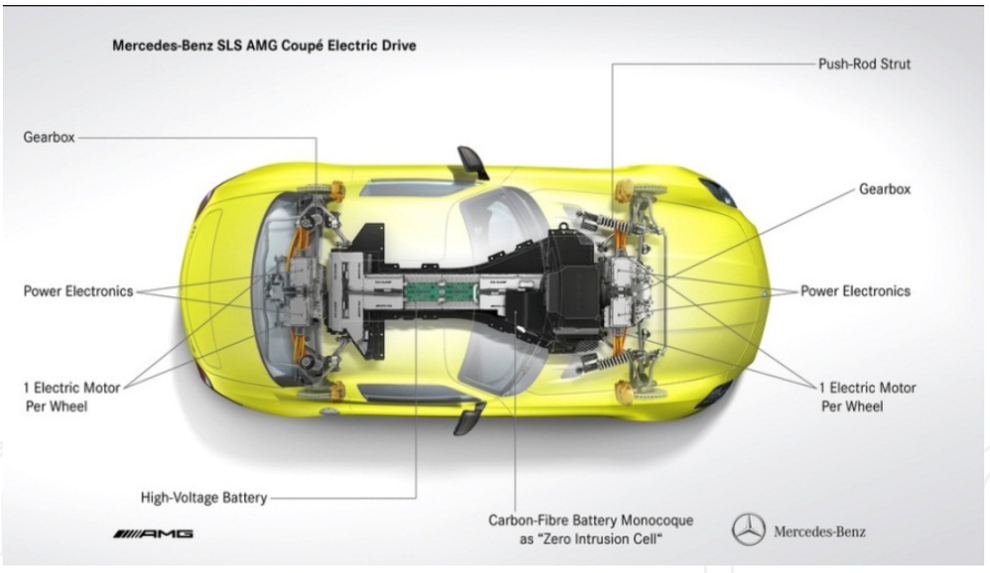


Figure 17. Today's high-speed EV system

5. Driving optimization

5.1. Comfort, information and safety

Minimizing electricity consumption is often in conflict with comfort and even security of vehicles and people. That's why new technologies are being used to increase safety and

comfort, and still energy consumption to be on a low level. Some of the current opportunities and trends are presented in here.

5.1.1. Computer control

Nowadays, computers are indispensable part of every vehicle. It monitors and controls virtually all vehicle functions, but also processed and displayed a lot of additional information, which significantly contributes to the comfort and safety. In EV that trend is particularly used. The vehicle is equipped with sensors that provide input data and further processed in a computer. The obtained results act on actuators, or the situation is shown on the display and the decision is left to the man [52-53].

Sensors are elements that receive and convert non-electrical signals into electrical. Temperature shift (translation, rotation, stretching), pressure, brightness, electromagnetic radiation, magnetic fields can be detected and can be converted. The temperature is the most usually measured as the non-electrical input, therefore many types of sensors are developed over the years. There are NTC (Negative Temperature Coefficient) and PTC (Positive Temperature Coefficient) resistors and thermocouples [52-54].

In modern vehicle, for the measurement of ambient temperature, cabin and equipment itself, semiconductor sensors are used. They are the product of modern technology of silicon (Si) integrated circuits, therefore also called Si sensors. Silicon sensors consist of integrated circuits using temperature-active properties of semiconductor compounds. All sensors can be with current or voltage output. In both cases, the output signal is proportional to the absolute temperature. The amplitude of the output signal is relatively high and linear, and the interpretation of the signals can be done without any difficulties. Si sensors temperature range usually is from -50 ° C to +150 ° C. The stability and accuracy of these sensors is good enough to allow readings with ± 0.1 ° C resolution. Thermal imager is used for more complex state visual monitoring used the [55].

For the measurement of other important physical quantities (pressure, force, position, displacement and level), sensors that respond to physical movement and / or movement are used. The most commonly used types are semiconductors and resistant strain gauges, linear voltage displacement transducers (LVDT), resistive potentiometers and capacitive sensors. Although each of these sensors is based on different principles, the output signals of all the sensors are voltage, current and impedance. These signals are directly or indirectly analog voltage expressed, so all the techniques described for the measurement are related to these transducers. Sensors that require external excitation reduce the accuracy of the measurement. Higher excitation levels provide higher levels of the output. However, the higher excitation increases internal power dissipation and measurement error, even with mechanical transducers. Each transducer has its own optimal level of excitation [54].

Flow and velocity quantities are measured using resistive, piezoelectric, thermal, and other transducers. As mentioned earlier, all methods ultimately provide as output an analog voltage, current, or impedance. Types of transducers, such as rotary encoders, turbine, magnetic and

optical sensors, have digital or pulse outputs. Speed or number of events can be determined by using digital counters and frequency meter [54,56,57].

Two-way communication between humans and computers is done through the touch screen display. Touch screen allows user to interact with a computer through touching the mark and the image on the screen. It is a visual electronic device that can sense touch and determine its location on the surface. The touch itself means contact between human fingers and the screen. The touch screen can also register contact other passive objects, such as special pens, styluses (used for greater precision and less contaminating the screen). Ability to register touch on the touch screen display depends on the implemented touch technology: ones can register just one touch and its position at a given time (single touch), others are capable of registering two or more simultaneous touch and their position on the screen (multi-touch).

Touch screen displays eliminate constraints on a number of discrete keys that are present in conventional membrane keypad. With a touch screen, combined with digital high-resolution display and integrated software[58-59], now there are virtually millions of switching options available for the user.

In commercial terms, touch screen displays, as devices with touch technology, make computer technology easy to use and accessible to all and also significantly to reduce time and cost of training of its use. They also provide much faster access to information as touch technology simplifies and speeds up the search process, which is crucial to driving. As an assembly that is mounted in front of a video display, touch screen display has an independent XY coordinate system that is calibrated according to the matrix display. To determine the location of the touch in the simplest implementation it requires two measurements, one to determine the coordinates of the X-axis and one to determine the coordinates of the Y axis. These measurements are then converted to the coordinates of the point of contact, which is then sent to the host (PC or microcontroller) via serial communication port [60]. A typical example of the application of TS and microprocessor technology is a GPS navigation system (Fig. 18) [61].

An example of a complete computer in a hermetically closed housing is shown in Fig. 19. Nexcom Company has released transport intended fanless computer - VTC-3300, for vehicles and fleet management [62].

5.1.2. Fire protection in EV

EV and HEV in particular have a lot of critical areas where it can get to the inception of fire. This requires a vehicle equipped elements of fire protection.

Central unit for fire detection and fire alarm, or as it is often called central unit for fire detection and its task is to power supply detectors and detection lines with stable and regulated supply voltage, which should be available in all expected operational situations, able to take a normal signal status, alarm status, interception line signal or removing the detector signal, short circuit signal, to signalize received state at the central unit and to forward signal to the sound and light devices and to ensure that the executive functions of the system that are required. Alarm indication at the control unit can turn on the respective light emitting diodes, or additional information through the display, but also by activating an internal audible alarm, buzzer or



Figure 18. GPS navigation system



Figure 19. Complete computer in a hermetically closed housing

horn. Today, the central fire protection unit connects to the computer, or it is incorporated as software in the computer system.

In addition to the central unit detection system must include detectors, alarms and detection and alarm lines, also the connections to the device that activates the sound and / or light alarms and executive functions. Network that connects the detection system elements is performed mainly by cables and its careful design and selection are essential to the quality, safety and value rationality of the system.

While in conventional systems alarm identification is with group of detectors, central unit and the person that receives information about the group (zone) that alarm is on, however with addressable system each detector gets its code (address) that identifies and tells to the central

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unit and to the present stuff its state. So the group identification alarm systems, the central unit receive information from a group of detectors (zones) of the alarm or some other event. Event means any change of state of the zone, such as an alarm, a signal failure, signal extraction detectors, fine lines and so on. Whereas in these systems, after the alarm of any zone a person in charge comes to the site, review of the protected object and determines the place where the alarm originated, the addressable system has been known for the receipt of alarms and place of origin, the detector that is in alarm state and the place where it is placed [54].

5.1.3. IR termography

IR thermography is a highly sophisticated measuring technique whose beginnings of extensive using coincide with the beginning of the third millennium. The reasons for this can be found in the fact that the thermography camera as a device that provides a visualization of thermal radiation would have to be consisting of many of the latest developments in science so that they become commercially available and easy to use. Very high breakthroughs in the field of sensors, thin films, optoelectronics, microelectronics and microcomputers are integrated and incorporated into these modern devices adapting them to the requirements of users in almost all areas of human activity.

The word thermography (literally, it would mean see the heat) explains the essence of this concept. Specifically, the point is that the appropriate devices (cameras) translate waves from the infrared region into a selected color of the visible part of the electromagnetic spectrum making them visible to the human eye. Different temperatures at the same time correspond to different colors and shades of colors and it is possible even to choose the color palette in which we want to show the resulting temperature map of the object [55, 63,64]. In modern vehicles is incorporated one or more thermography imagers and monitors the state of driver, equipment, or danger on the road in case of low visibility.

Camera which recorded persons in certain position is fixed, for example in front of mirror. Functionality of system is observed and recorded images were compared with literature data. Especially, it was taken care of record conditions: day-time record, time of taking drugs or active substance (coffee, alcohol, tea), room temperature, personal conditions such as emotions, satiety, hunger and physical activity. It was found that in normal conditions temperature in ocular region of healthy person does not exceed 36.3°C. In case of fever it is significantly higher. Thermograms of healthy person before and after vigorous physical activities show also the temperature changes in means of increase (fig. 20)[65].

The fact that thermography can detect very small differences in temperature gives the ability to detect the presence of persons (fig. 21), or animals (fig. 22) at night or in conditions of dense fog. Thermal detectors can function in the complete absence of any light. This makes them the perfect tool for observation in absolute darkness. Potential danger on the road in such conditions can be detected at a distance of 400 m for some systems, up to several kilometers, depending on the equipment and requirements.

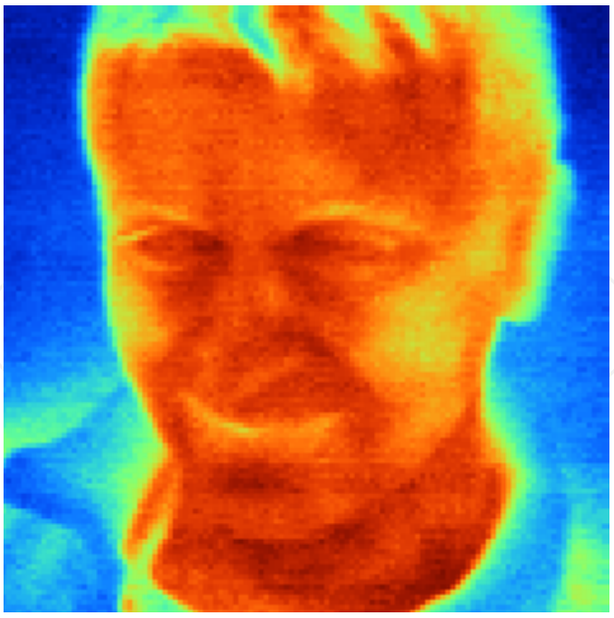


Figure 20. Thermogram of driver

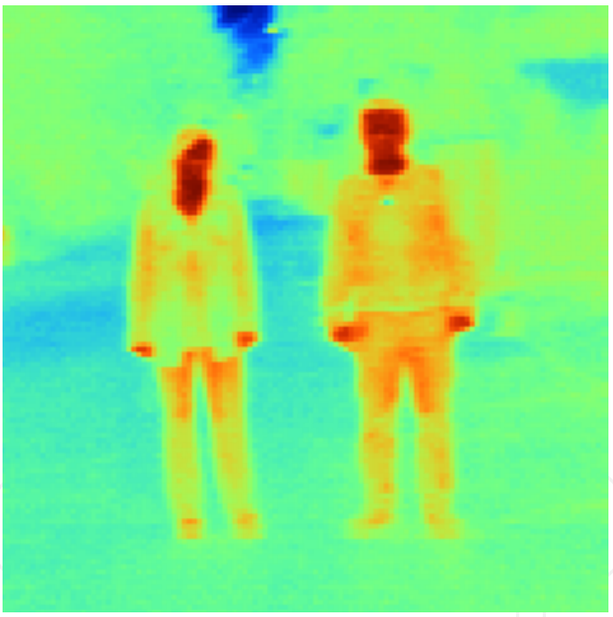


Figure 21. Thermogram of persons on the road

5.2. Route

Route optimization (RO) is an important feature of the Electric Vehicles which is responsible for finding optimized paths between any source and destination nodes in the road network. Recent researches perform the RO for EV using the Multi Constrained Optimal Path (MCOP) problem. The proposed MCOP problem aims to minimize the length of the path

and meets constraints on total travelling time, total time delay due to signals, total recharging time, and total recharging cost. The proposed algorithms need to have innovative methods for finding the velocity of the particles and updating their positions with accurate database of the requested roads[66-67].

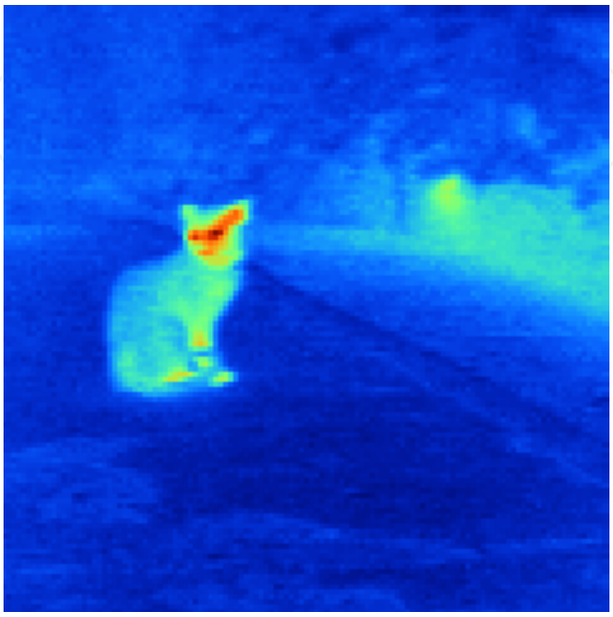


Figure 22. Thermogram of animal on the road

6. Conclusion

Electric drive vehicles are one of the most advanced vehicles at the moment taking into account contamination of environment. Lately there is an increased interest in the world for hybrid vehicles that have smaller fuel consumption and substantially less contamination emission footprint. Hybrid vehicles in most general terms can be described as vehicles comprising combination of energy producing and storing.

In this chapter, possibilities of energy savings in EV and HEV, energy generating in the vehicle itself and measures to improve comfort and safety are presented.

Therefore they must be combined with supercapacitors. Beside the development of standard technologies, development of power supply is crucial for EV. Accumulator batteries and fuel cells still have not reached the level to obscure enough for autonomy and meet the dynamic characteristics of vehicles. Supercapacitors are only available technology today that can provide high power and great cycle numbers at acceptable price. Supercapacitors have other properties that makes them interesting in hybrid vehicles, and it's ability of complete regeneration of energy of braking (so called regenerative braking), which increases energy efficiency, no special maintenance needed, great utilization of electric energy, small toxicity and easy storage after use.

Acknowledgements

This work was financially supported by the Ministry of Science and Technological Development Republic of Serbia (Projects No. 172060 and TR 32043).

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