MEĐUSOBNI UTICAJ RAZVOJA SKLADIŠTA ELEKTRIČNE ENERGIJE I RAZVOJA ELEKTRIČNIH VOZILA

CO-DEVELOPMENT OF ELECTRICITY STORAGE AND ELECTRIC VEHICLES

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U radu je analiziran uticaj mogućnosti „skladišta električne energije“ na razvoj i primenu EV. Prva saobraćajna vozila sa mehaničkim pogonom bila su pokretana električnom energijom. Devetnaesti vek su EV bila dominantna na drumovima, pa su čak i u prvoj trci motornih vozila pobedila EV. Početkom 20. veka počela je serijska proizvodnja ICE vozila na montažnoj traci i razvoj električnih baterija ostao je na nivou specifične energije od 15 Wh/kg. Infrastruktura za EV nije postojala van gradskih područja, što je doprinelo da krajem Prvog svetskog rata proizvodnja EV stane i ona postanu samo tehnička vozila. Kasnih šezdesetih i ranih sedamdesetih godina prošlog veka, dogodilo se ponovno rađanje EV podstaknuto zabrinutošću usled aerozagađenja i naftnim embargom od strane OPEC-a. Električne baterije su dostigle vrednost specifične energije od 35 Wh/kg. Uviđajući da EV još uvek ne mogu da konkurišu po svojim performansama vozilima sa IC pogonom, prvenstveno veliki proizvođači automobila su se okrenuli razvoju i prodaji FCV ili HV sa električnim baterijama koje su posedovale specifičnu energiju od 65 Wh/kg. Razvojem LIB sa specifičnim energijom od 200 Wh/kg stvorili su se uslovi da EV mogu svojim performansama da konkurišu postojećim vozilima sa IC motorima. Tek razvojem „skladišta električne energije“ sa specifičnom specifičnim energijom od 600 Wh/kg, ili više, moguće je izvršiti potpuni prelaz na vozila sa električnim pogonom.

Ključne reči: *Električna vozila, akumulatorska baterija, specifična energija, litijum-vazduh baterija*

The influence of the possibility of "storage of electricity" on the development and application of EV have been analyzes in this paper. The first traffic vehicles with mechanical drive were powered by electricity. In the nineteenth century EV were dominant on the roads, so even in the first race of motor vehicles EV were winners. At the beginning of the 20th century, the serial production of ICE vehicles on the assembly line began, and the development of electric batteries remained at a specific energy level of 15 Wh/kg. Infrastructure for the EV did not exist outside the urban areas, which contributed to the production of EVs stop after the end of the First World War, and after that they became only technical vehicles. In the late sixties and early seventies of the last century, re-emergence of EV was triggered by concerns about air pollution and oil embargoes by OPEC. Electric batteries have reached a specific value of 35 Wh/kg. Realizing that EV still cannot compete in their performance with ICE-powered vehicles, primarily large car manufacturers turned to the development and sales of FCV fuel cell vehicles or hybrid HV vehicles with electric batteries that had a specific energy of 65 Wh/kg. By developing LIB with a specific energy of 200 Wh/kg, conditions have been created for the EV to be able to compete with existing vehicles with IC motors. Only with the development of “power storage” with a specific energy of 600 Wh/kg, or more, it is possible to make a complete transition to electrically powered vehicles.

Key words: *Electric vehicles, accumulator batteries, specific energy, lithium-air battery.*

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Abrewations

AB	Accumulator battery
AC	Alternating current
Al-air	Aluminum air battery
BEV	Battery electric vehicle
DC	Direct current
ED	Electric drive
EP	Electric propulsion
EV	Electric vehicle
FC	Fuel cell
FCV	Fuel cell vehicle
HEV	Hybrid electric vehicle
IC	Internal combustion
ICE	Internal combustion engine
Li-air	Lithium air battery
LIB	Lithium ion battery
NiCd	Nickel cadmium (battery)
NiMH	Nickel metal hydride (battery)
OPEC	Organization of the Petroleum Exporting Countries
PbAB	Lead accumulator battery
PEV	Plug-in electric vehicle
SC	Supercondenser
SEE	Storage electric energy
Zn-air	Zink air battery
ZEV	Zero-emission vehicle

Electric vehicles (EV) don't have exhaust gases and don't create noise. They are powered by accumulative batteries (AB) rather than expensive oil, which have become increasingly smaller in the world. They therefore have certain advantages over existing ICEs, so it is believed that they will soon be replaced.

The beginning of the EP application in motor vehicles began much before the IC vehicles and marked the end of the nineteenth century. Nevertheless, the EV,s could not withstand the competition of vehicles with IC engines, which were faster, stronger and more robust. In addition to the fact that the efficiency level of the EV is significantly higher than the corresponding vehicle with an IC engine, one cannot ignore the fact that in the reservoir of the vehicle with an EV motor there is 44 times more energy than the EV battery. Until today, this has remained the main reason why there was no mass production and use of EV,s.

The introduction of EV into exploitation undoubtedly cleanses the environment where vehicles are used. However, in the case of EV, which are supplemented with electricity, carbon dioxide emissions are only transferred to the combustion of fossil fuels in power plants. The introduction of renewable energy sources such as the use of solar, wind and hydro potentials with the introduction of EV,s will ensure the transport of people and vehicles with zero emission vehicles. Great efforts are being made in the world to move in that direction.

1 The first energy storage and first electric vehicles - 19th century

As the beginning of the creation and use of EV, it can be taken in 1839 when Robert Davidson [1] from Scotland made the first electrically powered vehicle in order to replace steam locomotives, rated as noisy and dirty for smoke and coal. It EV on railways that moved on the Edinburgh - Glasgow line, about 130 km in length with one car and with a built-in yet primitive electric motor, used as a source of electricity the primary battery. The achieved speed was about 6.5 km/h, and the vehicle could not carry almost any useful load. Therefore, the use of this vehicle was very limited. Suitable AB was found by Gaston Plante in 1860, which allowed the commercialization of EV.

At the world exhibition in Berlin in 1879, Siemens showed the first practically applicable example EV [2], a small electric traction bike on the rails, which could pull three small wagons full of people. As early as 1882, a tram with an electric locomotive was carried out in Paris, so up to 50 passengers could ride these horse-drawn carriages. A few years later Tomas Edison constructed one of the first few better electromagnetic cars with nickel-alkaline batteries powered by an electric motor over 3.5 kW. Immediately then an electric bus was built.

At the world exhibition in Berlin in 1879, Siemens showed the first practical applied EV [2], a small electric traction tram on the rails, which could pull three small wagons full of people. As early as 1882, a tram with an electric locomotive was carried out in Paris, so that up to 50 passengers could drive in these carriages without horse. A few years later, Tomas Edison built one of the first better electric cars with nickel-alkaline batteries powered by electric motors with a power of about 3.5 kW. Immediately then an electric bus was built.

The first small-scale production of EV began in 1892 in Chicago. These vehicles were very unwieldy, but as such they had a very good passage with customers. They had the appearance of a chariot, with large wheels, without a roof, with a canopy that protected passengers from rain and sun. They were used for trips, in order to do some work, and even as a taxi for transporting more passengers. Passenger vehicles had engines of up to several kilowatts which allowed at a maximum speed of about 20 km/h crossing the distance and over a hundred kilometers with one charge of the rechargeable batteries. Series DC motors are usually used. The batteries were of high capacity, up to 400 Ah, voltage up to 100V. The share of the weight of the battery, compared to the fully loaded passenger car, was over half as well, allowing for such an autonomous radius of movement.

The first race of motor vehicles got EV,s. Five vehicles with an IC and two vehicles with an electric motor to run on a five-section road, each one mile long (1,609 m). The winners in all five sections were EV with an average speed of 43 km/h. A bright moment for EV in Europe was in 1899, when on May 1, EV in the form of a torpedo, called James Contente or "Dissatisfied", reached a speed of 100 km/h [3]. EV with weight of about 1,800 kg was constructed by Belgian Camillo Jenatzy. The next world record in speed was reached a couple of years later with a car owned by a petrol engine and the EVs never again managed to develop a higher speed than a vehicle with an IC engine.

Figure 1. External appearance of the first EV in the late 19th century

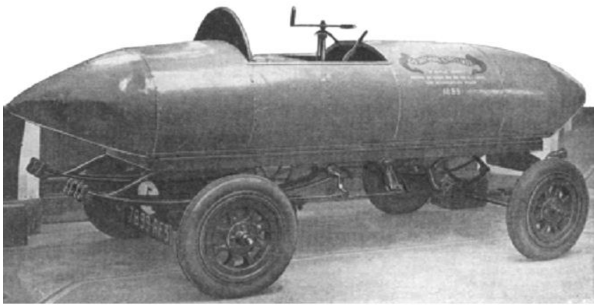

Figure 2. EV called James Contente, which in 1899 achieved an unprecedented speed of 100 km / h[4]

2 Further development in the first half of the 20th century

At the beginning of the 20th century, three types of motor vehicles with power units were used: petrol, steam or electricity. Statistics show that in the year 1900, about 8,000 cars were on the roads in United States, even 38% were with electricity. At the same time, by the third of the total, at that time there were vehicles with electricity, steam cars and IC vehicles.

The IC-motor car has gained increasing popularity due to its ease of charging, mobility, speed and autonomy, although the EV continued to pass. EV especially loved women, who considered the car with a gasoline drive dirty and more difficult to drive, and that was exactly the characteristics that men preferred to him, driven by sporty passion.

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The disadvantage of the then EVs was a relatively short range between charging the batteries. At the end of the 19th century, the specific energy in AB was about 10 Wh/kg. Already at the beginning of the 20th century this value was improved to 18 Wh/kg, so that only a decade later it would be 25 Wh/kg. In addition, refilling stations were not sufficiently diversified, although the situation began to improve at the beginning of the 20th century. However, the found sources of oil caused a low price of gasoline and the progress of the technique in the production of IC engines created the conditions for faster progress of these cars. Consequently, the evolution of EV remained aside. In the long run ride, from Beijing to Paris in 1907, petrol cars were definitely suppressed by steam vehicles and EV.

Soon interest in EV was lost, even in Europe, and the success of the IC engine was triumphant. EV performance compared to ICE vehicles was rather poor. The problem of batteries that were heavy and inefficient remained unresolved. The performance of cars designed for special purposes, with short radius of movement, could not be accepted for cars that could compete with those with a gasoline drive. After the end of the Second World War, electric drives remained largely reserved for special smaller transports and for vehicles most commonly used in the city.

In the seventies of the last century, the Renaissance begins with EV. The steady increase in oil prices, which ARE getting smaller, and the problems associated with its production and transport, leads to renewed interest in electric vehicles. At that time, coal and oil reserves seemed to be rapidly exhausted, forecasted at the beginning of the Third Millennium, and the "conservation of energy" began to be considered. In addition, continuous technical progress has provided high-quality and efficient speed control solutions for electric motors, lightweight batteries and lightweight body materials. Then in our country [5] we begin to work on the research and development of EV.

3 The last two decades of the 20th century

There are several directions of SEE development. The most promising direction of development is AB which has several types, parallel to the development of FC and SC. Further development of these systems is closely related to EV development.

A) Rechargeable batteries

The basic problem that accompanies EV is related to the "accumulated energy storage". Existing AB, despite being especially developed for this application, have a lot of deficiency in exploitation. Scientists' efforts are directed precisely to finding completely new principles for the SEE.

- Lead-acid batteries

During the 19th and 20th centuries, EV was fed from Pb AB. It consists of two lead plates immersed in a sulfuric acid solution. The nominal voltage of one cell is 2 V per cell. Specific energy is about 35Wh/kg, efficiency of 0.85 can handle up to 1,500 full charge and discharge cycles. There is no harmful evaporation in the gel battery, which means that maintenance is reduced as well as self-discharge.

- Nickel-cadmium batteries

NiCd batteries appeared a little later than Pb AB at the end of the 19th century. They consist of anodes made of cadmium and cathode from nickel hydroxides immersed in alkaline growth. The nominal voltage of one cell is 1.2 V per cell. The specific energy is about 45Wh/kg, can handle up to 1,000 full charges and discharge cycles.

- Nickel-metal-hydride batteries

NiMh batteries are similar to NiCd batteries, consisting of a positive electrode made of nickel-hydroxide and a negative electrode made of nickel alloy immersed in an alkaline electrolyte grid. Specific energy is about 60 Wh/kg and well tolerated overfilling and deep discharges, although their lifetime is reduced with rapid discharge. A negative feature is a memory effect.

- Lithium batteries

Li batteries consist of a positive electrode made of oxidized cobalt and a negative electrode made of an alloy made of nickel immersed in an electrolyte solution of lithium salt in an organic solvent. The specific energy is about 160 to 200 Wh/kg and has a long lifetime. Mana is a high price and a long time of replenishment, though better than most other batteries.

B) Fuel cells

FC is an electrochemical device that serves to convert chemical energy into DC. The principle of operation of this device is opposite to the operation of the electrolyzer and consists of two electrodes between which the electrolyte is. The electrodes are separated from the electrolyze by separators, so that gases, most commonly hydrogen and oxygen, are inserted into that space. Anode is oxidized and the cathode reduces fuel. The final reaction product is DC in the outer circle between the electrodes. For use in the EV, FC have many good features such as efficient fuel production, non-noise work, quick fuel refilling, durability and the ability to produce large amounts of energy. Disadvantage is still a high price.

C) Supercondensers

SC is electrochemical systems that store energy in a polarization liquid coating, in the interface between the ionic conductive electrolyte and the conductive electrode. The possibility of storing energy increases with the increase in the surface area of the interlayer. They have a greater specific energy and power than electrolytic capacitors - a device that stores energy as an electrostatic charge. They were developed as the primary power devices of additional power during acceleration or mountain driving EV, as well as for refueling during braking [6]. It is possible to use them as secondary energy sources in HV, accumulating energy while the vehicle is standing or during braking. An additional electronics is needed to maintain certain parameters taking into account the capacitor property to reduce the voltage at the ends of the capacitor linearly in line with the discharge energy.

3.1 Hybrid vehicles

Realizing that AB's problem has not yet been fully resolved to make EV more economically and technically more advanced than conventional vehicles, major car manufacturers, primarily Toyota, have developed HV.

Figure 3. Hybrid vehicle "Toyota Prius"

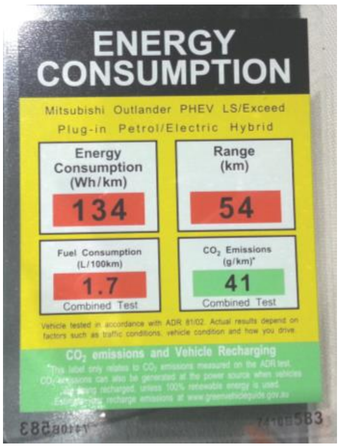

Figure 4. Consumption data for Plug-in hybrid vehicles

The development of energy electronics and inverters for controlling the speed and power of asynchronous motors, as well as NiMH, enabled the emergence of HV on the roads at the end of the 20th century. These vehicles enabled short-haul driving in city centers with pure electric drive and then driving and recharging the battery in the most convenient mode of operation of an IC engine. In this way, HV in the optimum mode of operation with the IC engine emit minimal emission of exhaust gases, while saving up to 20% of the fuel in city traffic [7]. So, hybrid vehicles are powered by an IC-powered electric motor to reduce exhaust emissions in urban centers or to improve the electrically driven driving range.

With up to 80 kg of NiMH batteries, which corresponds to the weight of one passenger, these vehicles could store about 4-5 kWh of electricity, which allowed them to pass a certain path, especially in the city core, with electric drive.

3.2 Electric vehicles with fuel cell

Some direction of EV development has been initiated by some car manufacturers to reduce environmental problems, ZEV vehicles that use FC.

EV with FC was named after having FCs to generate electric power to start the vehicle. Hydrogen is used as fuel in special high-pressure tanks. The energy obtained from this source is used to start the drive electric motor and the surplus energy is stored in AB or SC. These vehicles are rapidly complemented by hydrogen, and only water is obtained as a side effect of combustion. The main drawback of this type of EV is a significantly higher FC price than the IC engine, although there is a potential risk of leaking highly flammable and explosive hydrogen from the tank.

3.3 Plug-in vehicles

PV vehicles are ideal for urban exploitation conditions because they allow sufficient daily radius of movement in cities with a clean EP, which in most cases is sufficient for daily movement from home to work and back. When starting a longer trip, an IC engine delivering the necessary energy is put into operation.

Only the development of LIB created the conditions for starting to think about EV with much larger ranges. LIBs have a specific energy of 150-200 Wh/kg, which enabled PV to have a power of 10 - 20 kWh with 100 kg of batteries, which gives owners of these vehicles the ability to cross up to 60 km a day. The most commonly this is a sufficient daily radius to cross the way to work and back and again supplemented AB at home.

3.4 Battery powered electric vehicles

For cities that have environmental problems, BEV has been made. With the large-scale LIB production and a significant reduction in the cost of production, conditions have been created to start thinking about EV with considerably higher ranges.

Figure 5. Hydrogen Fuel cell car

6. Eco bus in Belgrade

Today's BEV has a mass of batteries between 300 and 450 kg and the SEE is about 50-80 kWh, which allows owners to cross the autonomous radius without recharging AB and over 300 km. In the most frequent daily needs of the driver, this is enough to meet the driver's multiple day needs.

It is interesting that SC also found a limited application for the BEV drive. Buses with city restricted radii of movement and the possibility of fast and frequent replenishment are used in Belgrade with satisfactory results.

4 Future development EV and AB

In the near future, Li-Air and Al-air are of special interest, primarily because of their high energy potential, due to the possibility of quick mechanical replacement of worn anodes and economics [8]

Significant results in the development of this type of batteries have been achieved in our country. In our laboratories, our scientist worked on the development of Al-air batteries with an anode of aluminum alloyed with small amounts of alloying components and with a neutral aqueous NaCl solution as an electrolyte [9]

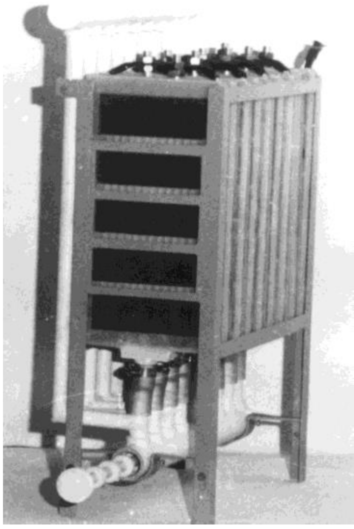

Figure 7. Prototype of the Al-Air battery

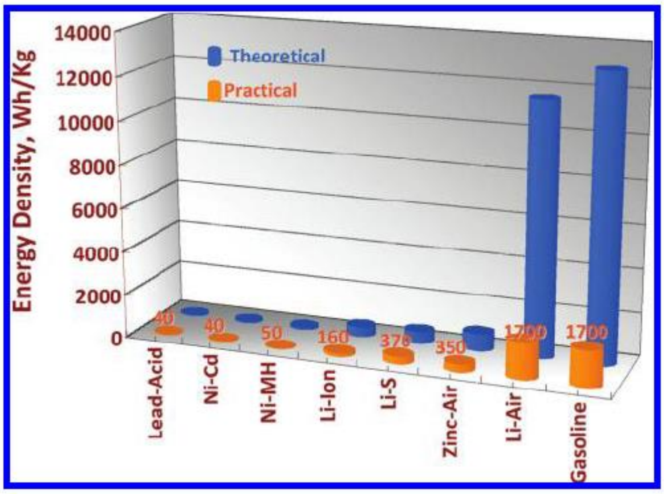

Figure 8. Specific energy of some batteries and gasoline[9]

The prototype of one such battery made 40 years ago is shown in Figure 7. This battery achieves a specific power of 34/39 W/kg and a specific energy of 170-190 Wh/kg at an optimum current density between 50 and 100 mA/cm^2, which on the current level of development of chemical sources of electricity is a battery of exceptional quality. The lack of battery is a relatively high price of the components used for alloying anodized aluminum.

The key criteria for the practical application of AB for EV drive are specific energy, price, lifetime (expressed in years of operation and mileage miles), and safety.

The specific energy of gasoline is 12,800Wh/kg, which is shown as the theoretical energy density in Figure 8. The average degree of utilization of passenger cars from the fuel tank to the wheels is below 15%, so that the specific energy of gasoline for automotive use is about 1,700Wh/kg. This is shown as a "real" specific energy for gasoline.

The degree of exploitation of the EP system (battery-wheels) is about 85%. The ten-fold improvement of the current specific energy LIB, which today is between 150 and 200Wh/kg (at the cell level), would lead to the equalization of the electric system with gasoline drive, at least when comparing specific energy. Oxidation of 1 kg of lithium metal releases about 11,680 Wh/kg, which is slightly lower than gasoline. This is shown as the theoretical specific energy in LIB. However, realistic specific energy for Li-Air batteries is expected to be significantly lower.

Existing metal-air batteries, such as Zn-air content, typically have a real specific energy of about 40-50% of their theoretical specific energy. However, it can be assumed that even a fully developed Li-Air cell will not reach such a superior relationship; fortunately, the realistic specific energy of 1700 Wh/kg for a fully charged battery corresponds to only 14.5% of theoretical energy content of the lithium metal.

Current research and development lead to the creation of an ultra-capacitor with a specific energy of 50 Wh/kg and a specific power of 1000 Wh/kg. However, ultracondensers also have some drawbacks. Based on the previous one, it can be concluded that the development of chemical sources of electricity is moving towards achieving the necessary source of electricity that could replace the IC engine with a relatively satisfactory economy of such a drive [10]

5 Conclusion

The first traffic vehicles with mechanical drive were powered by electricity. Although in the nineteenth century EV was dominant on the roads, their development was left neglected primarily due to inferior SEE specific energy of 15Wh / kg, so that at the beginning of the 20th century they fell into oblivion. In the late sixties and early seventies of the last century, the re-birth of EV was triggered by concern about air pollution and oil shortages. Soon all ED components were developed and SEE development continued. The evolution of the EV was conditioned by the degree of development of the reservoir of electricity, so that the HV use of the NiMH specific energy 60 Wh/kg energy was first developed and then an environmentally acceptable FCV that could not be economically sustained. PV starts to develop only when LIB specific energy of 150 Wh/kg. BEV has begun to develop when the price of these batteries is strong enough to appear under commercial conditions. In the coming years and decades, it is expected that the exploitable specific energy of the electricity storage will be converted from today's 200 Wh/kg to 600-800 Wh/kg, whereby the price per kWh of energy storage would fall by 50%, and then the conditions for the speed of car crossing with an IC-powered BEV.

At the end, we can conclude that in the 19th and 20th centuries, the development of energy storage dictated the development of EVs, and with the development of LIB, EVs began to dictate the rapid development of AB. In this, the market went from demand for AB to demand for BEV.

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