Electric and hybrid vehicles supply systems implementation problems

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Abstract. This paper considers the problems of construction or execution of rail contact or wireless charge cars. This includes the description of introduced system components, as well as the problems which can be faced during the development, construction and implementation in civil infrastructure. Also, the ways and possible usage of such methods of transportation are considered. The implementations of renewable sources or energy are preferable for such system, since the usage of electrical (EV) and hybrid electrical vehicles (HEV) directed of reduction of oil and gas consumption, as well as the reduction of carbon dioxide emission. The paper provides discussion about the expediency of different topologies of contact rail and wireless supply systems on the EV and HEV including.

1. Introduction
Today personal transport develops rapidly and continue to spread across the globe. This happened because of several things: comfort, mobility, ambition of people to free themselves from routine and addiction from other people, etc. In developed and developing countries this factor is in priority [1]. But also personal transport is used in in poor countries machines can execute much more mechanical functions such as transport goods, civil engineering, agriculture and so on. Nevertheless, there are a number of problems as most of the personal transport is consuming petroleum, which is lead to the exhaustion of harmful substances: nitrogen oxide, hydrocarbons, aldehydes, soot and benzo pyrene (Table 1). All of substances damage health not only of people but also damage environment [2].

![Figure 1. Increase of the oil price worldwide during last 30 years.](image-url)
Another issue in widespread use of such transport is that the usage of oil as a fuel becomes more and more expensive, this depends from different issues touches political and economic positions of countries and unions. But all of this goes from the fact that extract oil becomes more and more problematic as the stock of liquid oil decreases on the surfaces, and extract highly vicious oil demands more investments as well as extraction of oil from see shelf [3–5]. As it can be seen in fig. 1, the cost of oil increased three times average. As not every country can produce petroleum, due to the geographical and geological feature, they can’t follow such increase [6].

Table 1. The main Chemical Elements in The Exhaust gases

| Component          | Petroleum | Diesel |
|--------------------|-----------|--------|
| N₂, %              | 74-77     | 76-78  |
| O₂, %              | 0,3-0,8   | 2,0-18 |
| H₂O(vapor), %      | 3,0-5,5   | 0,5-4,0|
| CO₂, %             | 0,0-16    | 1,0-10 |
| CO, %              | 0,1-5,0   | 0,01-0,5|
| Nitrogen oxide, %  | 0,0-0,8   | 0,0002-0,5000 |
| Hydrocarbons, %    | 0,2-3,0   | 0,09-0,500 |
| Aldehydes, %       | 0,0-0,2   | 0,001-0,009 |
| Soot, %            | 0,0-0,04  | 0,01-1,10 |
| Benzo pyrene, %    | 10-20x10⁻⁶| 10x10⁻⁶ |

In this case many countries started to develop alternative methods of personal transports supply. One of the most successful attempts becomes the development of electrical and hybrid vehicles. Such countries as Germany, Japan, USA, UK, France and China already released big variety of such vehicles. But mostly they have hybrid type of engine. In present paper there will be described why such type of vehicles are more widely spread compared to pure electric vehicles and how this situation can be changes with new tendencies of automobile industry. In addition, here we considered ways of how to increase the efficiency of electric vehicles and reduce the pollution from petroleum and diesel personal transports.

2. Problems of hybrid and electrical vehicles

There are several methods of construction electrical vehicles:
- electrochemical accumulation energy: batteries and fuel cells;
- electric field energy storage: metal capacitors;
- aluminum electrolytic film large capacitors and capacitors;
- magnetic energy storage fields: superconducting electromagnet;
- the accumulation of kinetic energy: flywheel.

Let us consider the disadvantages of such technologies, as nowadays all of them stops the progress in developing more autonomous cars. The most popular types of batteries nowadays are li-ion and acid-lead batteries. Also there are: nickel metal hydride, nickel-cadmium and molten chloroaluminate sodium (NaAlCl₄) as the electrolyte. Production of such batteries balancing in quality of the charge and discharge characteristics and the costs. The best and well-known type is lithium batteries. But through their per unit cost this can’t be used in every electric car, as in increases the cost of such an engine. Tesla cars – are case in point. Their popularity grows, still not as much as it can be, due to its cost ($68,000 – $138,800). Also lead acid batteries can’t produce current in deep discharge [7].

Lead acid batteries significantly cheaper (150€/KWh against 700€/KWh). Still if we consider the fact that the lead acid batteries can handle much less cycles of charge/discharge, there payback is close to the lithium-ion batteries. Still the worst problem as their specific weigh to amount of power they can have (100 W per kg compare to 500 W per kg). So this too heavy for long travel in pure electric car (539 km – Tesla Model S). With average everyday travel on the car – one charge will be not enough for even 5-6 days. This situation is close to modern mobile phones that need to be charges very often.
To extend the life cycle of batteries the NiMH (nickel-metal hybrid) batteries were developed, which can have more than 1200 cycles of discharge. Still these batteries are more expensive compared to Li-ion. Another problem of most types of batteries – as low temperature. For example, for Li-ion batteries it is 5 – 25 degree Celsius. During the wintertime in northern countries in such working conditions, the resource of battery decreases more than twice.

Another way of storing energy in vehicle is usage of capacitive plane-parallel capacitor on a metal film. Metal Film Condensers have very high-power density, usually from 100 kW/kg to 1 MW/kg, very low specific energy consumption then there is less than 0.1 Wh/kg. The reason for this is that the effective plate densities are not very large, since they are essentially a plane-parallel system. Total discharge time plane-parallel capacitors range from microseconds to milliseconds. A small amount of stored energy makes metal film capacitors useful only for limited number of devices. Still such technology is not popular due to the issues in energy control of such devices. Also the energy can’t be stored for the long time, as it’s density in the battery high.

Nowadays, electrolytic capacitors are very common due to their high capacitive density [F/ m3], compared with metal film capacitors. They are called electrolytic capacitors because the dielectric is formed electrolytic process. The most common type of electrolytic condenser in the industry is an aluminum electrolytic capacitor that wears out over time, and usually serves for 2 to 3 years before what will require replacement. Large Capacitor - Electrochemical device, it accumulates energy electrostatically and not electrochemically as accumulator battery. Breakdown voltage high capacity electrolyte capacitors low (below 3 V), which limits their practical application and reduces the required power. Large Capacitors have a very long service life, to 100,000 cycles, with a cost of approximately $ 500 / kW. This makes this technology very attractive but needs specific control devices.

The magnetic energy storage is accumulating energy in a magnetic field. Due to the high resistance of non-superconductors, the coil flow cannot be high enough to accumulate significant amounts of energy.

Superconductors have three critical parameters: current density, magnetic flux density, and temperature. Practical superconductors are usually made of NbTi or Nb3Sn multithreads embedded in copper or aluminum stabilization matrix, which is also used to absorb energy in case the superconductor suddenly becomes an ordinary conductor.

In addition to the problem of inductive resistance, there is a problem with capacitive resistance. The inductive resistance increases with frequency of current, where capacitive decreases. As the inductive charge supposed to be wireless, concept is shown in fig. 2 there will be significant gap between source of energy and receiver, the capacitance will be big. To reduce it, there is need to be high frequency and isolation which will increase resistance of inductance. In both cases (low and high frequency) there will be significant voltage drop [8].

Figure 2. Wireless car charge concept.

The last way of energy capacity is usage of the flywheel. To not consider mechanical issues of such method (big amount of moment change cycle during start/stop with the following material fatigue)
will demand very special construction of engine and transmission, so it will not be in focus in the presented paper.

3. Contact Rail Electrical Vehicle Concept
Certainly, in HEV these problems are partially solved, especially considering the recuperation of energy during stops of vehicles. Also, HEV solving the problem of extreme pollution of environment (excepting problems of batteries utilization) reducing it to normal level. Still the oil extraction cost should be considered for the future. Here we presented the contact rail concept for EV.

This idea widely spread nowadays in railroad transport, for massive amount of people transportation. Still this can be used also in personal vehicles. There are several varieties of realization: classic (contact wire), supply rail and wireless contact rail.

First one is used everywhere (trains, trolley bus) but not good for the mobile EV or the electric poles need to be constructed on every street. With all the researches in this area still this is one of the good variant of supply system.

Another idea is to use special road surface with implemented contact rail. Such concept is already realized in Sweden in 2018. The idea is to transport energy while it is moving to the vehicle via contact rail (fig. 3). This road is only 2 km long for tests. This is fully contact so the source can produce current of any frequency which is neglecting the problems described above [8].

The contact itself produced by special device on the bottom of the vehicle and has the same problem of mobility as a contact wire. Still with the large amount battery with the combination of such road surface can solve the problems of demands in charge stations from which EV and very demandable. Such concept ideal in the area where the moving cycle of vehicle is always the same such as load and upload of on the opencast mines.

On the highways it is offered to make a dedicated line with such contact rail, so the vehicle can connect to it during the movement and charge the battery. Still it is need to be changed the construction of contact with the road, to provide mobility on the road. As it is need to be fixed contact to the contact rail, the content surface would be fixed.

The moving leg with energy consumer for such cases can fix issue. This leg can have all three degrees of freedom for free moving and also to telescope where there is no source of energy or car changes its position in traffic. Still for such system the control system should be developed. There is a variety of methods to control position of contact leg, among them the most efficient is the control by current flow to the battery.

The contact leg due to the friction should be made from durable and low-resistant material or can levitate close to the contact rail with little gap (close to the gaps in electrical machines). Such method of supply will demand careful research, as to fix leg on the height of 1 mm or less is the work of control system and mechanical execution [9].

The full concept of such idea will be considered in next papers, as also presented the calculations and comparison of methods.
4. Electric Road (Pavement) Concepts

There are several Electric road (pavement) concepts.

Solar roads

The Dutch company has developed a road surface using solar panels. The principle is simple; photovoltaic cells that generate electricity are protected by glass on top and are located on a concrete base with a rubber layer. Glass besides allowing light to get on the photocells has properties like asphalt; due to this it is durable, has no glare and has non-slippery stability. Each unit is connected to a central system from which the generated electricity is supplied to the network. This coating can withstand the load at which a 12-ton truck can safely drive on such a road.

In April 2014, the first non-volatile solar-powered car parking was commissioned in Idaho. A small area of the solar road can generate 3600 watts of energy. As in any installation of this type, the amount of energy produced is directly proportional to the intensity of solar radiation. Therefore, the efficiency of the panels will be different depending on the geographical area of installation. The work is blown on the improvement of new technology in road construction, seeking to improve the efficiency of the system. The fact is that the solar road consists of panels whose photovoltaic layer makes up only 69 percent of the tile surface area. It is planned to bring this figure to almost 100 percent. Engineers expect to optimize the production process and move to the stage of industrial production innovation of road construction.

![Figure 4. Photovoltaic material for solar roads.](image1)

![Figure 5. Solar road coat for the electric cars supply.](image2)

Transient voltage recovery simulation

Dutch company announced its plans to build plastic roads, which are built on the principle of the LEGO constructor. Rotterdam will be the first city in the world with roads from factory plastic plates.

The PlasticRoad project is considered by its developers as a “green” alternative to asphalt — the modules of the new pavement will be made from recycled plastic bottles. However, this road has one unpleasant feature, which is that the coating can slip when wet. The company VolkerWessels - the
According to VolkerWessels, plastic pavement requires less maintenance than traditional asphalt and is able to withstand more extreme temperatures from -40 to +80 degrees Celsius. VolkerWessels points to a lightweight plastic coating, a smaller load on the ground, as well as simplified access to utilities under the road. The company hopes that the new approach to construction will help reduce problems during road works.

In addition, the construction of plastic roads takes weeks, not months. The project also aims to make a significant contribution to improving the environmental situation in the world. According to the company, asphalt accounts for 1.6 million tons of global CO2 emissions annually, which represents 2 percent of all harmful emissions from vehicles.

The project is still in the conceptual stage, but as promised by VolkerWessels engineers, within three years they will be ready to begin its implementation.

**Figure 6.** Concept of module plastic roads.

Smart roads

Russian designers are proposing to introduce the Smart Roads into the practice of new-generation roads. The “intellectual” road glows in the dark, warns drivers about the appearance of dangerous areas, monitors the status of traffic and responds to problems, “recharges” and “recharges” cars as they move, and so on, that is equipped with the latest science and technology. According to the plan of the designers, “smart” roads will be much more functional, more convenient, safer and more environmentally friendly than modern roads.

One idea is to apply road markings using special photoluminescent paint. During the day, the paint absorbs light energy and is thus “charged.” And at night - "gives" light to the environment. There is enough energy for more than 10 hours, which will be enough to not leave the drivers without the necessary lighting.

Another idea is to create special periodic sections of the route, prompting drivers of weather conditions overboard of their car, highlighting on their surface certain symbols warning of snow, ice, drifts and so on. They are also applied with a special “dynamic” paint, which begins to emit white light when the temperature drops to zero degrees. Not to notice such a warning is simply impossible.

A “smart” road can act as a huge road sign or help a driver to drive around a traffic jam, constantly maneuvering the dimensions of parts and sidewalks. The GPS system integrated into the road, indicates the driver's way with the help of huge arrows that will move in front of the car and lead it to the right place. Roads will be able to detect trespassers, drawing attention to it with the help of a circle of LEDs around and accompanying it with a light ring during the entire movement on the roadway, warning other drivers about the danger.

To recharge the batteries of electric vehicles on the “smart highway”, special induction lanes are designed. The basic idea is the ability to charge electric vehicles while driving using wireless charging. Induction coils have been introduced into the pavement, which interact with similar coils on the bottom of electric vehicles (or hybrids) and recharge the battery.

The “smart” road will be made of three layers of coverage. The first layer, the top one, is made of high-strength waterproof materials that can withstand the daily stresses of passing cars. The material is translucent, for passing sunlight, charging the battery cells. The second layer is equipped with
sophisticated electronics: it integrates a microprocessor board that is responsible for lighting, communications, control, warning of breakdowns and other tasks. The third layer is designed to distribute energy throughout the road, and to protect microprocessors from moisture.

Here it is need to be discussed a couple of disadvantages of «block» system that can be implemented in a smart roads concept. One of the ideas was to recycle already used plastic to shed it and reform it to compressed blocks, which are robust and durable. But there is a sophisticated issue that can lead to some damage. Studies [10] reveled that reprocessing of some types of plastic emit toxic gases like CO2, acetone, formaldehydes, ethylbenzene and acetaldehyde. So while the electrical vehicles and their hybrid versions and called to reduce CO2 and other emissions (table 1), the production of the surfaces for them can nullify all the profit. It is need to be discussed how to recycle plastic waste without any emissions so far. Nevertheless plastic roads are tough in low temperatures, the not well process plastic load suffers from the temperatures above 120o C [11].

All these concepts can be applied in future highway roads, as it demands an enclosed supply system. Moreover, such innovations cost much and the payback from these technologies still under the question.

5. Comparison of Cars on the Electric Motor, Hybrid Engine and Internal Combustion Engine

To confirm the idea of priority of electric car usage let us compare EV and eternal combustion engine cars.

Electric cars have several advantages and disadvantages compared to cars on the engine and hybrid cars, which results, however, now in the advantage of hybrid cars over the rest.

Comparing the economy today you can get such a picture. For an average passenger car, consumption per 100 km of run is 24.4 kW-h in an electric vehicle, 57.53 kW-h in a hybrid vehicle, 82.62 kW-h in a gas vehicle, and 75.24 kW in a gasoline and diesel car. From here it is clear that the electric vehicle is the winner in terms of economy [12].

Considering the characteristics, the motor has an almost perfect characteristic (dependence of the shaft frequency on the torque), which is graphically close to the hyperbole (fig. 7).

![Torque-speed characteristics of electric and ICE motors](image_url)

**Figure 7.** Torque-speed characteristics of electric and ICE motors.

This is to some extent the merit of a simplified transmission. Some cars have a single-stage gearbox, while others have an electric motor mounted in the wheels. All this also allows you to do without a bulky gearbox. Unlike an electric motor, an internal combustion engine in a working frequency range has a directly proportional characteristic (see figure), and after reaching the nominal values, an increase in shaft rotational frequencies leads to a drop-in power. To extend the range of frequencies and plodding force used gearbox. For hybrid cars, things are a little more complicated.
Since they work, then as an electric motor, then as an internal combustion engine, this and correspondingly requires adaptive transmissions capable of operating in a large range of transmission ratios (more than 20, when it does not exceed 6-7 for vehicles with internal combustion engines), this in turn complicates the device transmissions (fig. 8).

![Figure 8. Hybrid transmission main types.](image)

If we consider the infrastructure for each type of car, then we can come to the conclusion that if a car with an internal combustion engine or a hybrid can refuel almost anywhere, due to the developed infrastructure, then for electric vehicles the situation is more pitiable. If in developed countries, the network of charging stations is large enough for owners of electric vehicles to feel comfortable (for example, in China there are 161,000 stations in 2017, in the USA 16,000 stations in 2017, in Japan 40,000 stations in 2015, in Great Britain 11736 in 2016, in Germany, 7407 at the end of 2016, in France, 2689 in 2017). Then in other countries there are much fewer such stations, especially in economically unstable (for example, in Russia there are 42 stations in 2017, in Belarus 1 in 2017, in Ukraine 104 for 2017). This shows that the distribution of infrastructure for electric vehicles occurs mainly in developed countries (and mostly in the top ten most developed). This, in turn, limits the wide distribution of electric vehicles by these countries [13].

6. Supply Problems in Contact Rail Electrical Vehicles With Renewable Energy Sources

To provide electrical energy to the cars though the roads the supply system should be constructed. As the goal of the EV and HEV mostly – reduction of pollution and reduction of fuel cost, it will be profitable to use the renewable energy sources. In different areas different sources will be profitable. For example, in Saint-Petersburg (Russia) such concept can be tested on the North West Diameter which partially is situated on the big opened area (bridges and countryside), also big average wind speeds dictate the priority to the windmills usage. Still it is need to be calculated how much power should be produced to fully charge vehicles. Here is two ways to equalize the load and the energy production [13].

The first is to implement large bank of batteries near the road. Renewable energy sources depend on the weather and for windmills for example can be situations with big traffic and no wind, so the cars will consume stored energy. Average car demands around 170kW power, if there is no traffic jam, the cars should be in 20-50m from each other, so there is 20-50 cars in one traffic line. This leads to the 3.5 – 8.5 MW of energy production. To cover such demand for one hour, there should be around 1000 batteries with 700 Ah capacity and 12 V voltage, which will cost 670 thousand of euros according to the average prices in specialized shops. This for the 1 km of the road, so this system is very high cost even with rough calculations. In addition, it is needed to be added the price of the control system, renovation of the road surface and windmills itself (3-4 on every kilometer of the road).

As an example, let us consider the Toyota Prius restyled 2018, hatchback, 4th generation, XW50. Engine power is 99 hp, which means 72.81 kW in translation. It is known that the average power
delivered by the engine is 75 kW. This is taken as the average value.

A typical car cycle consists of: starting the engine, accelerating, speeding, braking and stopping. After which the cycle repeats.

Peak power consumption is starting the engine, because when you start it is powered by a battery. In our case, this is not essential, since the installation of a contactless battery charge on a high-speed stretch of road is considered. The main aspects to which we need to pay attention - acceleration, high-speed movement and braking.

![Figure 9. Speed vs power consumption characteristics.](image)

Energy is spent to both impart acceleration, and with a uniform ride to overcome rolling friction, air resistance. The fig. 9 shows that during acceleration on a flat road up to 60 km/h, the power barely reaches 20 kW, at 80 km/h about 25-30 kW. When the speed decreases, the power either drops or becomes negative, which indicates energy recovery. The efficiency of this conversion is about 50-70%, which has a good effect on the "life" of the battery on one charge.

In three lanes in one direction at a speed of 80 km/h, there may be 90-120 cars, subject to speeding, braking when rebuilding and accelerating at a convention, this leads to 3.15-4.2 MW of energy. Each machine consumes an average of 37 kW. Part of the energy is returned due to recovery during rebuilding and braking for the exit. Since the plot is speedy, the recovery efficiency is not high and reduces energy consumption to 35 kW.

Still in such concept the batteries inside the car can be much smaller as the specific capacity continues to grow annually and the cost of each car will be significantly lower. Another way to solve this is to use batteries in cars, so they can be less dependent from source of energy. But in this case the batteries should be extended. The point of where such concept is profitable for customers should be considered in future papers, as well as the methods of supply, supply control system and payback time.

If we look at the growth dynamics of the specific capacity of batteries (fig. 10), then by 2028 it can be counted on a capacity of about 310 Wh/kg. This will significantly reduce the weight of the car, since it will be possible to “pump” 25% more energy into the battery, as well as the cost of electric cars [13–15].
7. Conclusion
The auto industry is developing very slowly in the direction of replacing existing cars on organic fuel, since the direction of electric vehicles is expensive to produce. In my opinion, you need to start with hybrid versions of HEV, gradually shifting the role of fuel. It is better to make small but sure steps than large and unnecessary ones.

The EV and HEV industry continued the development of more efficient methods of supply and more durable battery for longer travel. Still for now there is no any significant signs of the scientific breakthrough. So, there need be considered alternative ways of supply such cars as the problems of pollution occupies minds of more and more countries with following enforcement of the environmental laws.

Also, it shouldn’t be forgotten about the various accessories of the car. A stationary vehicle, operating radio, screens, phone charge +400 watts; included headlights +400 watts; air conditioning at full capacity with a minimum temperature of 18 degrees - about 2.7 kW. If we take the average value, it will be about 14-16 kWh / 100 km. It is also worth considering the efficiency of recovery with a half-empty battery, which increases the efficiency to 11-14 kWh / 100 km.

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