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MODELLING HYBRID POWERTRAIN OPERATION OF A WHEELED VEHICLE INCLUDING DUAL POWER SOURCE

The paper presents a way of modeling hybrid drive system with a dual source of electricity. The use of such a solution is to use better used and flow of energy in hybrid vehicle. Describes the sizing of electrochemical batteries per unit weight of a wheeled vehicle and the system was adopted to supporting the super-capacitor batteries. Presents a concept of switching multiple units in a hybrid system, which adopted the criterion of engine rotational speed and linear speed of the vehicle.

1. INTRODUCTION

In 1992 in Rio de Janeiro The World Summit on Organic "Earth 2000" the most industrialized countries (which was also Poland) have committed themselves to mid-century to reduce CO_2 emissions by half from the state in 1987. This had an impact on, the ongoing fuel crisis in the seventies of last century. The world realized then that the natural resources of energy, so called conventional fuels, are limited and must look for new solutions of energy production. Currently it is believed that there is a greater risk of contamination of the environment, than the possibility of depletion of petroleum resources derivative of natural resources. Reducing emissions of harmful products of combustion processes is a key task of environmental protection. This can be achieved by reducing the demand for energy derived from traditional fuels, thus increasing the energy generation from renewable sources in overall energy balance in the country, and thus the world. To "clean" energy sources include: biomass, solar radiation, gravity drop of water, wind [1],[6].

Alternative energy sources do not negatively affect (or only slightly) on the environment, but only some are used for providing energy to drive the wheeled vehicles. Restrictions related to their use may be classified into several groups [1],[6]:

- technology - due to the character of their occurrence and the possibility of practical use,

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- economic - associated with large financial outlay for their use in wheeled vehicles,
- political or legal.

The use of energy from renewable sources is not a new solution. Historically, the energy processed in the windmills, or watermills. However, only the energy crisis, and with it the abrupt increases in oil prices, and later also other fuels, have contributed to the growth of interest in new, alternative energy sources and alternative generation technologies cheaper and more environmentally sound energy. Hence, energy can be divided into two groups [1,6]:

- renewable,
- non-renewable.

Environmental considerations and the Kyoto Protocol signed in December 1997, concerning the prevention of climate warming, contributed to a significant human interest in renewable energy. For 10 years, you may notice a rapid movement of investment in alternative energy sources. However, most of alternative energy is too expensive and at present it is impossible to adopt such a source of energy for propulsion of wheeled vehicles. Also, storage of energy used to drive an electric vehicle still requires many years of research and the search for such sources of magazines that could compete with the fuel energy value relative to its weight. As the author of the work [4], currently used electrochemical batteries would weigh about 7.5 tons to the energy accumulated in them, then weighed 50kg energy derived from gasoline. The lesson here is that electric vehicles at the moment are not a perfect solution, however, contribute to the tremendous development and progress in the construction of new energy-efficient and eco-wheeled vehicles.

2. ELECTRIC VEHICLE

A typical drivetrain in an electric cars is equipped with an electric motor, control system and a battery (energy storage). Such a system is characterized by [7]:

- good control parameters,
- a relatively quiet operation,
- inoperative engine when the car is stopped,
- very good characteristics affecting the need for traction..

The primary task of driving is to produce a sufficiently high torque which can move the vehicle forward or backward. The electric or hybrid wheeled vehicles uses only certain types of electric motors (Fig .1).

Due to the dynamic properties of a wheeled vehicle is the best characteristic of this engine, at which its power is independent of vehicle speed. This condition is met by using "the constant power hyperbole " - curve 1 in Fig. 2. Today's engines have similar driving characteristics precisely to the curve. This applies to both electric motors and in part the internal combustion engines. The easiest way to approximation of the characteristics of the engine to this curve is the use of mechanical transmissions. As for electric motors, the most similar characteristics to the curve of the hyperbola, are serial DC motors.

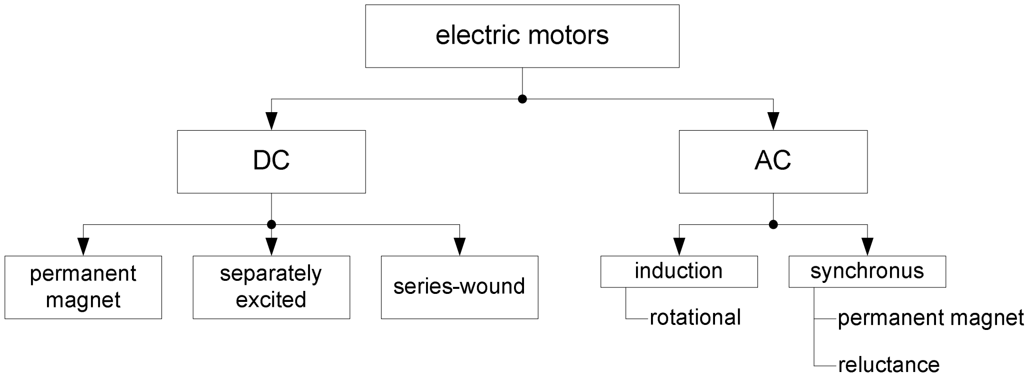

Fig. 1. Electric motors used in hybrid vehicles [7]

Wheeled vehicles equipped with electric motors have a very good characteristic "speed driving force." Fig. 2 shows the characteristics of the electric motor and the ideal characteristics of the traction machine. You will notice that electric motors have an almost ideal characteristics of a driving force occurring on the wheels of motor vehicles.

DC electric motor has, unfortunately, a number of operational defects, which include primarily brush and mechanical commutator, which resulted in limiting the maximum speed. Also, the relatively high unit weight adversely affects the use of a DC motor, a traction machine in wheeled vehicle.

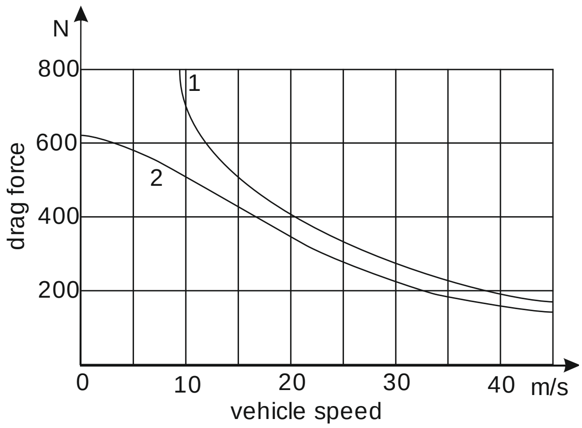

Fig. 2. Dependence of the driving force to the vehicle speed, 1-ideal characteristics of a fixed maximum power, 2-car features an electric-powered [1]

A huge development has been made in electronics semiconductor, and large capacity of induction motors AC resulted in increased interest in using these units, as the traction drive systems used on wheeled vehicles. Low unit weight and very high efficiency, amounting to even 95% makes the wheeled vehicle equipped with such an engine, characterized by small mass changes on its own (do not include weight of batteries), better characterization of power and torque characteristics and very good traction. The reason for inhibiting the development of alternating current motors, electric drives as wheeled vehicles, it is difficult and costly technique of converting DC to AC.

An important aspect of use the electric propulsion units is a problem resulting from a complicated method for controlling the unit and know-how the energy flow. The problem becomes even more complicated when we are dealing with a hybrid vehicle equipped with a petrol engine and electric motor. Control algorithm in this case is very complex.

In modern cars, it is important to the growing number of additional electrical equipment, resulting in continuous growth in demand for electricity. More and more it consumes not only extra equipment but also by modern engines. Engines with direct fuel injection need three times more energy than a unit of non-injection powered. The demand for electrical power of today's medium-sized vehicles is about 1kW, and peak 3 to 4kW.Given the steady increase in power consumption, it is considered that in the near future, this demand could be as 4 to 5kW and a peak power up to 15kW. That is why many car companies (Bosch, Delphi, Siemens, Valeo) tries to meet this demand and develop future power systems. It was found that the optimum voltage will amount to 14 / 42V, because the current standard alternators gain voltage 14V, and 42V equal 14V × 3. For security reasons, the optimum is three-fold increase in voltage, which causes a threefold decrease in the current in order to obtain the same power. This means the smallest loss of energy, reduced load on joints and contacts, the ability to use electrical wires with smaller diameters. Installing the 14V will be used to illuminate the car radio power, sensors and receivers do not show a tendency to peak power. The installation of 42V will be used to start the motor, the fan drive mechanism, power steering and air-conditioner. This solution was adopted in the algorithm control of the wheeled vehicle shown in Fig. 3.

There will also be introducing hybrid vehicles (HV - Hybrid Vehicle), vehicles equipped with fuel cell (FC - Fuel Cell) and electric vehicles (EV - Electric Vehicle), where electricity demand may reach a value of more than 40kW.

3. HYBRID VEHICLE – THE DESIGN CONCEPT

Future drive solutions necessitate increased interaction between conventional systems and electric propulsion systems. Presented in fig. 4 velocity characteristics of the drive units can notice the difference torque when driving at different RPM. For the AC asynchronous motor, the maximum available torque is achieved at a speed not much lower than the maximum, and the stable operation of asynchronous motor is in the range for which the slip s_k equal to the moment and the maximum slip s = 0 for which the asynchronous motor is not producing torque. Effective use of this type of engine to drive a wheeled vehicle is possible only by using appropriate electronic controlling circuits the operation of the engine - so called inverters.

The supercharged internal combustion engine operating characteristics are more favorable to drive a wheeled vehicle. The maximum torque in internal combustion engines is available in a range of rotational speed of approximately 1,500 to 4,500 rpm, practically in the range of 50% of the total speed is available maximum torque. Unfortunately, internal combustion engines require the use of additional mechanical gearbox, which is associated with a very small value of the effective rotation.

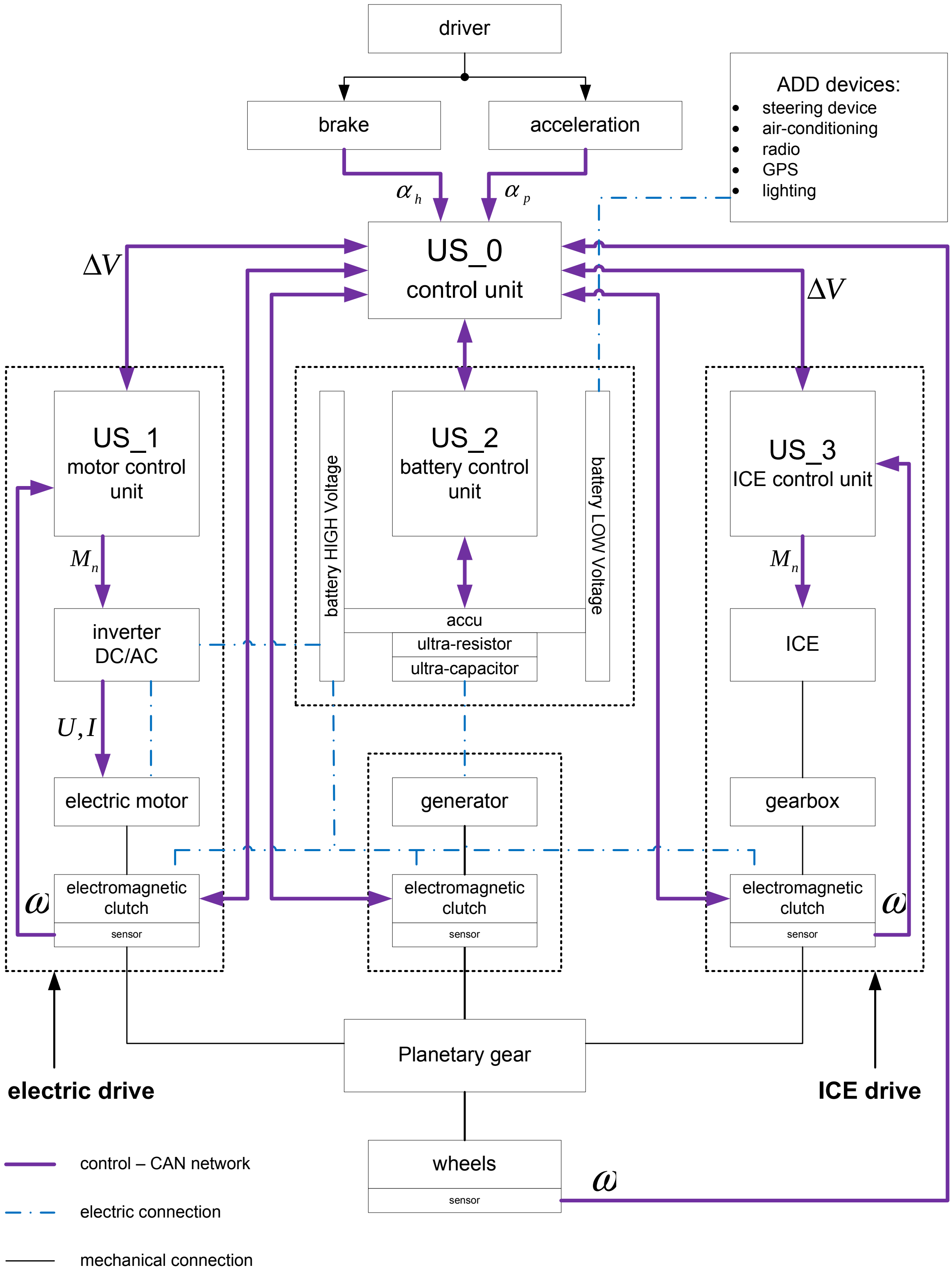

Fig. 3. Concept control algorithm of hybrid vehicle [3]

An important parameter is the range of a wheeled vehicle expressed in km. It is the way they wheeled vehicle can travel using an energy stored in batteries and fuel.

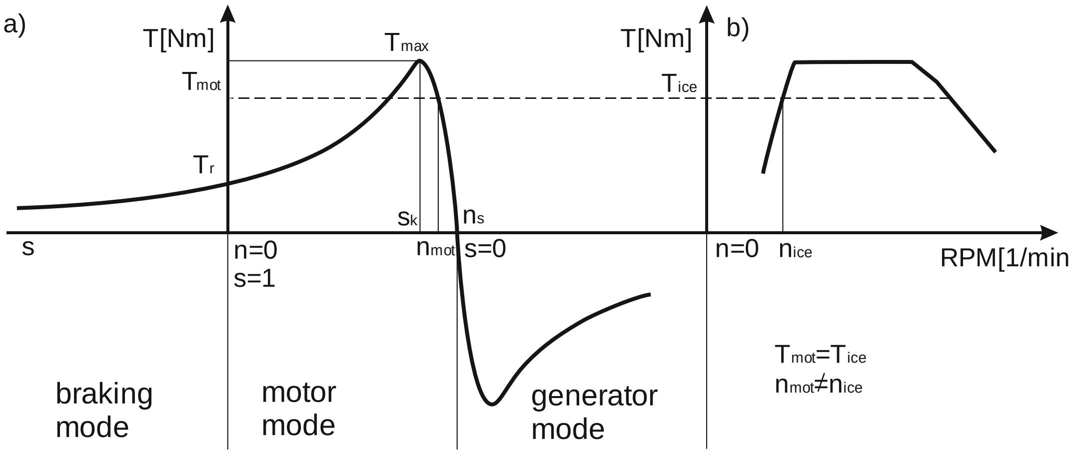

Fig. 4. Comparison of the torque curve of the petrol engine and electric [1],[5]

Moving with constant speed wheeled vehicle on a horizontal road and no wind loads obtained the largest possible range of energy supplied to the drive. If the vehicle is moving according to a specific driving cycle, constant acceleration, braking, stopping, for example, move in urban areas the use of stored energy to drive the vehicle is much smaller. In such conditions, the vehicle clears the shortest distance by consumption energy stored in batteries and fuel. It is therefore important to develop such a process use energy to increase the range of the vehicle and thus the efficiency of the propulsion system. For this purpose, used a recuperative braking, which allows for recovery of energy lost during braking. It is also appropriate deployment of ICE and electric units that type of vehicle traffic. Proper engine operation at a certain speed and load guarantees the lowest specific fuel consumption, which translates into less pollution.

An important parameter in the description and modeling of these phenomena is the unit energy consumption of the wheeled vehicle, expressed in $\left[\frac{kJ}{km}\right]$ or in $\left[\frac{kJ}{kg \cdot km}\right]$. In the second case also takeed the weight of a wheeled vehicle, which directly translates to the selection of suitable mass of individual elements constituting the propulsion system.

Consider the example of moving a wheeled vehicle in urban areas, where the main power source is valid only and only the electric motor. Power for the electric motor is derived solely from electrochemical batteries, and importantly, the vehicle is not equipped with a recuperation of kinetic energy.

Range y of such a vehicle for the movement established at a constant speed can be expressed by the formula:

$$y = v \cdot t \; [km] \tag{1}$$

where:

v – vehicle speed $\left[\frac{km}{h}\right]$,

t - time taken for a fixed range, which is also a real time discharge the electrochemical battery $[h]$, That time t in the consideration is accepted as a real time discharge electrochemical battery differs from the nominal time of discharge electrochemical battery t_n [h]. The real discharge time t is directly related to its energy state, and you download from the shock or power. If the actual discharge time t referencing to the wheels of the vehicle to obtain the following relationship:

$$t = \frac{E}{N}\ [h] \tag{2}$$

where:

N - real power of unit discharges as a function of vehicle weight $\left[\frac{W}{kg}\right]$,

The real power of unit discharge $N\left[\frac{W}{kg}\right]$ differs from the rated power output of discharge electrochemical battery N_n [W], which corresponds to 1hour battery discharge.

By Peuckert inference:

$$\frac{Q}{Q_n} = \left(\frac{I}{I_n}\right)^{-\beta} \tag{3}$$

where:
Q, Q_n – real and nominal battery capacity [Ah],
I, I_n - realny i nominal current of the battery discharge [A],
β – Peuckert factor,

could be determined from a very close approximation:

$$E = E_n\left(\frac{N}{N_n}\right)^{-\beta}\ \left[\frac{kJ}{kg}\right] \tag{4}$$

$$N = v \cdot R\ \left[\frac{W}{kg}\right] \tag{5}$$

where:
R - the total strength of resistance to motion of a wheeled vehicle as a function of vehicle weight$\left[\frac{N}{kg}\right]$.

From the above formulas can calculate the value of a hypothetical range of wheeled vehicle moving along a horizontal road at a constant speed without acceleration and braking. In fact, this situation is not found to be produced and moving the vehicle, its acceleration and braking, which translates to higher specific energy consumption. Acceleration of a wheeled vehicle solely on electricity motor at the horizontal road and no wind load can be expressed with the following relationship:

$$a = \frac{N}{v} - R \left[\frac{N}{kg} = \frac{m}{s^2}\right] \quad (6)$$

where:

N - power output as the drive wheels of the vehicle, the corresponding part of the real power of electrochemical battery discharge unit delivered to the wheels as a function of vehicle weight $\left[\frac{W}{kg}\right]$,

This power can be converted at the battery terminals with dependency:

$$N = N_n \cdot f \cdot \eta_n \left[\frac{W}{kg}\right] \quad (7)$$

where:

N_n - real power density of battery discharge corresponding to real time as a function of battery weight $\left[\frac{W}{kg}\right]$,

f - vehicle load factor of electrochemical battery mass,

η_n – efficiency of drivetrain

$$a = \frac{N_n \cdot f \cdot \eta_n}{v} - R \left[\frac{N}{kg} = \frac{m}{s^2}\right] \quad (8)$$

Coefficients N_n, η_n, R vary nonlinearly as a function of speed and time, also speed is also changed. In summary, these theoretical issues concerning the designation of the operational performance of wheeled vehicles powered solely by an electric motor, such as: range, specific energy consumption, accelerating the ability to allow the calculation of these parameters.

Of course, it must be assumed that the speed can influence the increase or decrease the overall consumption of energy:

- increase the speed increases energy consumption through aerodynamic drag, which is connected directly to the vehicle's aerodynamic properties,
- increased speed reduces energy consumption by increasing the efficiency of the power unit.

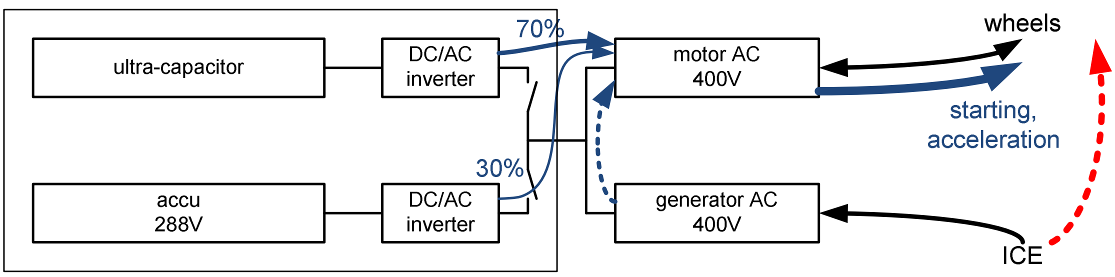

Fig. 5. The concept of an electric motor drive when starting and accelerating [2]

With the above assumptions is very difficult to determine the ideal (lowest) energy consumption, since many factors must be examined for a particular type of vehicle wheel and for the particular type of electric motor. Everything is further complicated when we add the variable road conditions by which it is impossible to determine the lowest energy consumption.

For example, suppose a hypothetical wheeled vehicle moving at a constant speed consistent with the parameters:

- vehicle weight – 1225 kg,
- specific energy of electrochemical battery– 22 $\left[\frac{\mathrm{W}\cdot h}{\mathrm{kg}}\right]$ = 79,20 $\left[\frac{\mathrm{kJ}}{\mathrm{kg}}\right]$,
- vehicle load factor $f = \frac{m_a}{m_p}$ – 0,346 (rechargeable battery has a weight of more than 400 kg),
- constant speed of the vehicle – 40 $\left[\frac{\mathrm{km}}{h}\right]$,
- total force of the resistance movement – 0,262 $\left[\frac{\mathrm{N}}{\mathrm{kg}}\right]$,

which, after substituting the above formulas can be calculated:

- range of the vehicle – more than 100 km ,
- driving time to fully discharge the battery – about 2 h 35 min.

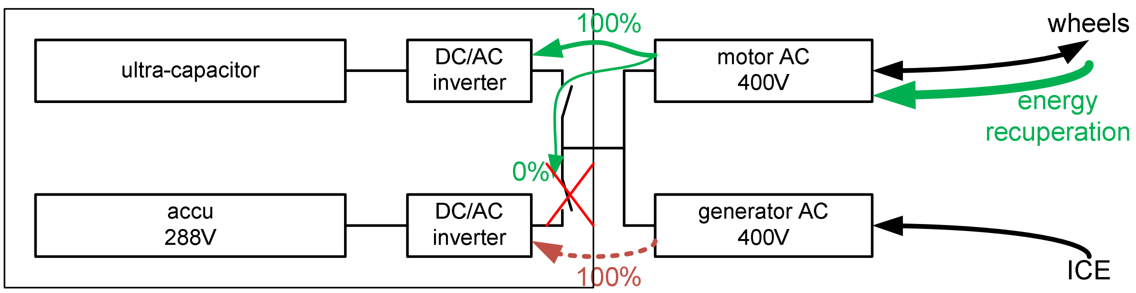

Fig. 6. The concept of recovered vehicle kinetic energy [2]

The above example shows that the wheeled vehicle powered only by an electric motor powered only by an electrochemical battery, has a very small range. Therefore, at present wheeled vehicles powered only by electric motor waiting for an design solutions for new batteries. Using the petrol engine and an electric motor could reduce vehicle weight while increasing its range. Using additional energy storage likes super-capacitors can effectively use energy from the recuperation vehicle kinetic energy during braking. This translates to an additional reduction of weight of electrochemical batteries, while increasing the dynamism of the car. Concepts such solutions represent the next two diagrams.

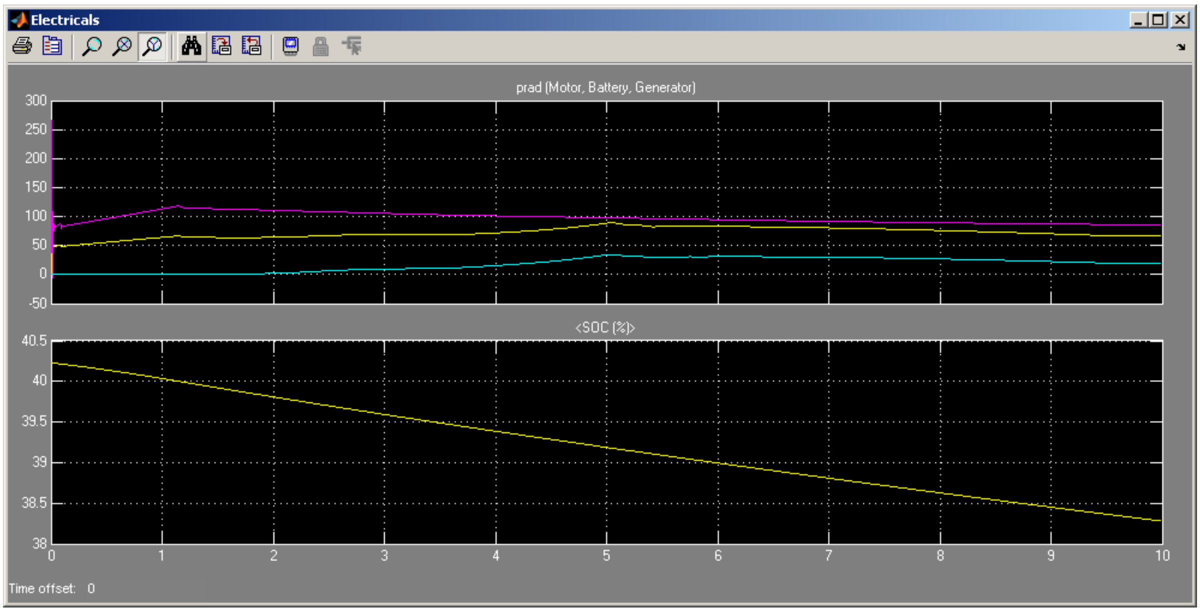

Fig. 7. The simulation results of electrochemical batteries and super-capacitors in the software MATLAB / Simulink

4. CONCLUSIONS

In this paper presents the conceptual approach to the problem with recovery of vehicle kinetic energy. The presented system receiving energy from the recuperation loads only by the super-capacitors, which protects the electrochemical battery from damage. Also describes how sizing up battery to power the electric motor of the unit weight. This helps to determine quite precisely the size and weight of electrochemical batteries in your type of vehicle traffic.

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