On the possibilities of the application of the energy storage and hybrid drives in the railway transportation

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Abstract: An importance of the application of the energy storage and hybrid drives in the railway transport has been shown in the contribution. The usefulness of the selected types of the energy storage devices has been discussed. Some examples of the successful application of these devices in the railway technology have been described.

Key words: energy storage, railway, hybrid drives, energy efficiency

1. Introduction

One of the most important problems of the present time transportation is an energy consumption and/or greenhouse gases reduction, especially the energy consumed by transport means. It can be realized in a few different ways according to the vehicle construction, type of the power train, energy transformations necessary to the vehicle motion.

The first area where essential energy savings could be reached has been a railway transport. Locomotives with maximum power of a few MW, heavy freight trains with the total weight of some thousand tonnes gave an ideal opportunity to utilize advantages of the electric traction. The first technical solutions of the energy regeneration during train breaking were invented and applied practically in the first years of the electric traction. Electric motors, switched to the generator regime, sent back the electric energy to the overhead line. However there was a necessary condition to utilize the regenerative braking: the other locomotive running on the same traction section had to take over the energy – the regenerative energy had to be utilized. If no other locomotive was able to consume the regenerative energy the braking locomotive had to be switched to the classical pneumatic regime of breaking. The other solution was to send the regenerative energy back to the primary high voltage supply system. If power supply system was AC type this way of the energy utilization was simple and could be realized directly. In the case of the DC power supply system there was a need of applying special DC/AC devices – it became possible when power electronics reached the suitable level of development.

A utilization of the regenerative energy would be also possible if the energy could be stored during regeneration and given back during the next start or the next acceleration of the vehicle. For this reason some storage devices, described in the next chapter, should be used. They can be stationary (so called centralized storage devices) or mobile, placed directly on the vehicle. The first case is possible when the vehicles are dependent on the external energy

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source – for example electric locomotives connected to the contact line. A discussion of these two above mentioned basic possibilities has been presented in the paper.

Stationary devices have worked since 1981 in Japan (Keihin line – 15kWh flywheel storage device with DC control system and the later one, with the storage capacity of 30 kWh, with AC power train [1]. The biggest battery storage device, used in the passenger transport power supply system, has been built in Berlin [2]. In the 1990s a stationary energy storage device was installed in the supply system of the mountain railroad [3]. The second solution – mobile, or on-board, energy storage devices were installed, for the first time, in New York subway in the early 1980s [4]. At the same time an AC electric wagon with a big battery storage device operated in West Germany [5]. On-board energy storage device was installed in traction unit "Coradia-Lirex" presented in "Innotrans 2000" exhibition [6]. Many other similar examples can be found.

2. Energy storage devices

A comparison of the main types of the storage devices, characterized by the two last defined parameters is shown in Fig. 1. The best specific power properties have so called super capacitors and flywheels. However their specific energy is rather poor. On the other hand, gasoline, methyl alcohol and hydrogen used as fuels in the internal combustion engines have about 100 times higher specific energies and 1000 times lower specific power.

![Fig. 1 Basic parameters of some storage devices [8]](image)

The present resurgence of interest in flywheels centers on complete systems incorporating not only the flywheel energy storage device, but also a motor-generator and power conditioning electronics together with an interface to the application. The realization of the practical system requires effective use of high strength composites, high remanence permanent magnets, power electronics for variable voltage variable frequency (VVVF) machines and high speed bearings with an ultra low coefficient of friction. These technologies are melded together by use of modern engineering techniques including system architecture computer simulations and analysis. Example of the device of this type can be found in [9]. Presented device is capable of 700 kW for 5 seconds which is equivalent to 3.5 MJ of the stored energy. The gross weight of the device is 159 kg, the main outer dimensions are 0.81m x 0.61m x 0.56 m (L x W x H). A combination of a few devices can be used to obtain the proper energy storage parameters.
Several California companies are racing to develop ultracapacitors with the energy-storage capacity a few orders of magnitude higher of traditional capacitors. Ultracapacitors store and release energy like batteries but have hugely longer lives. They can unload their energy 10 to 100 times faster than batteries but store less energy. That makes them ideal for use with batteries. Ultracapacitors also could be used in conjunction with small gasoline-powered generators to create clean vehicles with high-performance and tremendous fuel economy. A target of 80 miles per gallon (3.5 l per 100 km) in prototype cars should be achieved within a few years. Scientists at the Lawrence Livermore National Laboratory have invented an exotic carbon material called aerogel, the lightest substance known. Four cubic centimeters have the same surface area as a football field. Aerogels have a wide range of uses, among others it could be an ideal material for storing ions. When two strips of aerogel bonded onto aluminum are separated by a thin insulator, they become an extremely efficient capacitor.

A number of battery technologies exist for use as utility-scale energy storage facilities. Primarily, these installations have been lead-acid, but other battery technologies such as sodium sulphur (NaS) and lithium ion are quickly becoming commercially available. Rechargeable lithium batteries are becoming increasingly popular for powering electronic equipment; they are also of interest in the longer term for electric vehicle (EV) applications. Their light weight and high energy density could help increase vehicle range, and their components are relatively inexpensive. These batteries make use of a metallic lithium negative electrode; a polyethylene oxide based solid electrolyte, and a metal oxide positive electrode. Studies are led to obtain cheaper, higher capacity nickel-metal hydride batteries. These batteries are very important to the industries because they have long cycle life and are more environmentally acceptable than nickel-cadmium batteries. Adding certain elements to the nickel-metal alloy greatly increases the battery capacity—and thus the vehicle’s potential range. However, these additives make nickel metal hydride batteries prohibitively expensive. Investigation of the relationship among the added elements, alloy structure, and electrochemical performance should make possible to find less expensive additives that would provide the same — or even greater— battery capacity and performance.

3. Some technical solutions of the energy storage in transportation systems

Among the first there was a flywheel energy storage substation located on the Keihin Kyuko Line in Japan. It started operation in November 1981. The device was intended to collect and store excessive regenerative electric energy to the flywheel installed in the electric railway substation and to supply electric energy to the contact line when the DC substation current output was rising. The apparatus also made possible a compensation of the voltage drops at the extreme end of the overhead line by means of a switchover of the control mode. A new generation of flywheel energy storage devices dedicated for use in Cologne light rail network has been described in the AC machine’s rotor with permanent magnets is situated at the flywheel bore. Overall storage device efficiency is 91% including power electronics and bearing losses. A compact design with the RPM operational range 8,000 … 15,000 min⁻¹ ensures storing of 6.6 kWh regenerative energy. Estimated annular energy savings thanks to the surplus regenerative energy storage are about 300 MWh per year. An additional advantage of the device application is a significant peak current and energy flow shaving which in consequence gives about 50 kW decreasing of the average DC supply substation power.

A new type of battery-dominant hybrid technology has been developed for the railway. Switcher locomotive service is characterized by highly variable power output use. This variability in demand is exploited to allow the use of a significantly smaller, fuel efficient,
A low maintenance engine and generator combination to supply energy to the traction motors and to the application-engineered battery pack. A demonstrator vehicle, the Green Goat®, has been designed, tested, constructed and put into field trials for 18 months in various locations and types of service, with very good (performance and operational) results. RailPower’s Green Goat® battery dominant hybrid locomotive is well suited to switching work and can be seen as an excellent application for hybrid vehicle technology. The locomotive uses a massive, cost-effective lead acid battery that is maintained by a fuel efficient, low emission, Tier 2 compliant diesel engine. It easily supports the burden of the conservative battery design that is long-life and has a high round trip efficiency by virtue of its size. One of the reasons that hybrids are more efficient than their non-hybrid counterparts, is that the prime mover that powers the vehicle can be selected for efficiency and not be compromised by power requirements. Switcher locomotives spend most of their time in the lower notches and at idle. Fuel consumption reductions in the order of 30-80% have been observed during RailPower’s trials on several different properties with the Green Goat® compared to locomotives they replaced.

4. Conclusion
The examples presented in the contribution show that the application of the energy storage devices in the railway power supply systems can be technically and economically effective. The following similar applications can be expected.

Literature