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RECUPERATION ENERGY SYSTEMS IN ELECTRIC TRANSPORTATION

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Abstract: *Methods and facilities which can be used for storage inertia mass energy of electric traction vehicle. If recupered energy can't be absorbed immediately in other vehicle, that energy must be aborded or accumulated. Storage equipment is profitable located nearly the place, where vehicles change speed. There're not problems with power dissipation of traction mains and special-purpose vehicle. Storage equipments are formed on mechanical base or electrical base. Electrical-based storage equipments use super capacitors. Mechanical-based storage equipments use gyrostats. Confrontation of storage equipments and possible technical arrangement say, that super capacitors are better then others.*

Key words: *Amtee, Pilsen, University of West Bohemia, electric traction, super capacitor, power accumulators, balance wheel*

INTRODUCTION

Increasing claims of optimal managing of electrical energy in traffic are reason to increase consumption and price of electrical energy (inclusive of trams, trolleys, tube trains).

The costs of electrical energy are essential part of operating costs. For example costs for electrical energy of tram are 750 000 CZK per year and for tube train are 4 500 000 CZK per year. Previous researches proved that vehicle in use losts 40% of whole consumption of el.energy.

An advantage of vehicles modern traction is possibility to change a kinetic energy to electrical energy and sent it back to contact line. Recovered energy have to sent back to contact lines or to another vehicle immediately. In most cases is impossible to sent energy back so it must be used in brake resistors or mechanical brakes.

A sufficient accumulation of recovered energy at the moment of impossibility of consume is a significant streamline of electric traction´s operation. Let me to describe some new trends in development of suitable power accumulators used in electric traction in following lines.

1 ACCUMULATORS OF ENERGY SUITABLE FOR OPERATION IN UMT (UMT-URBAN MASS TRANSPORTATION)

We can find some solutions and forms for accumulation of energy. The most suitable solution is put the energy to magnetic, electrical field form or in chemical form. Least suitable solution is put the energy to kinetic energy form of body or condensed gas. An disadvantage of two last mentioned forms is an increaseable risk of losts energy in spite of changes primary forms of energy to kinetic energy or gas energy.

I would like to engaged you in accumulators which are determined of theirs qualities to good co-operation with traction line of city railway in following paragraphs of this article. The most monitored qualities of those accumulators are: ability of assume enough quantity of energy (for tram is necessary quantity of energy about 1-3 kWh), a sufficient dynamics of receiving or expenditure of energy (it is need to be about 700 kW for tram), high efficiency, energy density [Wh/kg] and a specific capacity (if we use a mobile accumulator). The most suitable accumulators which have aforesaid qualities are: capacitor batteries-based accumulators, supercapacitors batteries, electrochemical cells and high-speed wheels.

1.1 Electric accumulators

You can see a comparision of important parameters of electrical accumulators in *Tab 1 - Tab 3*. If you want to have a complete imagination about demands on accumulator, you can find common parameters of braking and drive away of tube trains and trams.

parameter	value	unit
charging time	$10^{-3} – 10^{-6}$	sec.
discharging time	$10^{-3} – 10^{-6}$	sec.
specific energy	0,1	Wh/kg
specific output	100 000	W/kg
operating life	500 000 and more	cycles
effectivity of charging and discharging	95 and more	%

Tab. 1: Parameters of capacitor-based accumulator

parameter	value	unit
charging time	1 - 5	hour
discharging time	0,3 - 3	hour
specific energy	10 - 100	Wh/kg
specific output	1 000	W/kg
operating life	1 000	cycles
effectivity of charging and discharging	70 - 85	%

Tab. 2: Parameters of electrochemical accumulator

parameter	value	unit
charging time	0,3 - 30	sec.
discharging time	0,3 - 30	sec.
specific energy	1 - 10	Wh/kg
specific output	10 000	W/kg
operating life	500 000	cycles
effectivity of charging and discharging	85 - 98	%

Tab. 3: Parameters supercapacitor´s accumulator

type of vehicle	tram	tube railway
starting time[s]	12 -15	25 - 30
braking time [s]	10 - 13	20 - 25
weight [t]	do 70	do 360
kinetic energy[kWh]	1 - 3	10 - 20

Tab. 4: Characteristic parameters of vehicles

Classical capacitor is unsuitable to use for its low density of energy. Accumulation equipment accumulator-based will be very capacious and usage in vehicle will be impossible.

Electrochemical accumulator is more suitable than classical capacitor but it has some disadvantages: doesn´t posses qualifications on dynamics, length of charging and discharging cycle is too long (a few hours), it´s not suitable to medium term, peaked cycle which we need.

The most suitable accumulator for its parameters is supercapacitor. Supercapacitor which is steady placed on vehicle riding on frequently tram-line (about 270 trams per a day – it matches to Pilsen´s tram-line No.4, for example) has long working life – about 5 years of running.

Let´s think of that only one tram consumes electrical energy in total value of 750 000 CZK per a year. We can store up about 40% of total value of energy and 65% of stored energy we can utilize again (35% of losses include transmission of energy by contact line, losses in converters and influence of its charging and discharging cycle). Storage equipment placed on vehicle running on tram-line (in our case it´s tram-line No.4) can save 260 millions CZK.

Previous technical economic balance sheet proved importance of be engaged on practical applications supercapacitors accumulators in electric traction, especially in case of frequently tram-lines.

1.2 Electromechanical accumulators

Electromechanical accumulators are next interesting equipments used for storage of energy in electric traction.

A development of technologies in recent years is reason to realize solutions and settlement of accumulators. A realization of settlement and solutions the accumulators was only theoretical-based in past.

Working principle of electromechanical accumulator consists in transformation electrical energy to kinetic energy (velocity head), energy of rotation. Energy of rotary balance wheel is determinated by equation (1). From this equation is derived present-day trend of high-speed wheel.

$$E_K = \frac{1}{2} \cdot J \cdot \omega^2 \qquad (1)$$

explanation to equation (1): J = *moment of inertia of balance wheel*
ω = *rotating speed*

The aim of development is set up a slight balance wheel which have minimum losses and will be able to accumulate plurality of energy. A modern suggestion of balance wheel exploited an advanced engineering solutions.

The whole body of balance wheel is placed in a firm vacuum case – this is reason to reduce losses of accumulator caused by balance wheel friction by air.

The balance wheel is adapted for working in high rotational speed. It is made from fibres (material which bodies of balance wheels are made has large breaking length l_t). Breaking length is rate of tenacity of material in tension (σ_p) [MPa] and material density (ρ) [kg/m^3].

$$l_t = \frac{\sigma_p}{\rho} \qquad (2)$$

If the balance wheel is compound of suitable material running of balance wheel is safe till 100 000 revolutions per minute (r.p.m.). When the only one fibre will break a massive case wouldn´t be suffered.

The balance wheel is structured as ring. There are permanent magnets inside of ring. The ring is slipped on a stator winding. A structure of balance wheel matches to synchronous machine with permanent magnets. You can see a structure and a description of balance wheel on picture *Fig.1*. A gear of this type balance wheel is laid into the balance wheel.

A whole rotor is carried by superconducting levitation bearing, which is situated in thermo insulation case inside of the main case of balance wheel. A bearing length of rotor is supplemented of a contact friction bearing for an advance safety in service – the friction bearing is used as emergency brake in this case.

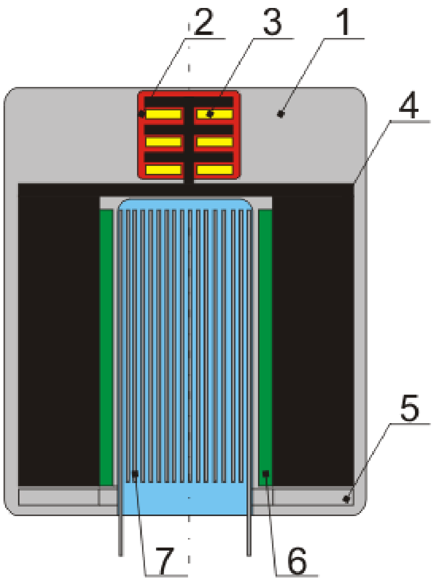

Fig.1.

1. *The main vacuum case*
2. *Thermo insulation case (there are cryogenic conditions in case)*
3. *Superconductive apporting bearing*
4. *Body of balance wheel*
5. *Emergency frictional and breaking bearing*
6. *Permanent magnets*
7. *Stator winding with vacuum bushing terminals*

High-speed wheels are very expensive and complicated equipments nowadays. A frequently application more high revs is not economical to use in surroundings of tram-line electric traction. But in the future could be balance wheel use for storage king-sized energies (in orders of MWh) in power grids. Balance wheel which will be applicated in power grids will have a similar function as transfer power stations.

2 ENGINEERING OF SUPERCAPACITOR ACCUMULATOR

Supercapacitor is the most suitable accumulator for utilization mentioned above.

Supercapacitor accumulator is the most suitable accumulator of recuperative energy for its technical simplicity and economically advantageous.

2.1 Structure of supercapacitor cell

Supercapacitor is two-layer electrochemical capacitor similar to classical capacitor, not too much similar to electrochemical cell. Function of supercapacitor is based on electrostatical charge operating. Typical two-layer supecapacitor structure is mentioned on *Fig. 2.* Supercapacitor is compounded of: positive electrode made from aluminum foil (1), plies of active electrode (2), separator (3), negative electrode made from aluminum foil (4).

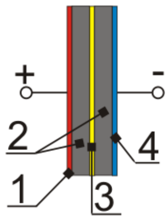

Fig. 2.

There are ions equalized in conductive fusion, in liquid or gel electrolyte. Electrolyte is situated between electrodes. Negative ions will be going to positive electrode and cations will be going to negative electrode after the connection the supercapacitor to voltage - it will be lead to specular distribution of ions. A extension of incoming voltage is modified by value of dissociation voltage. The cause of using operating usage of value 2,3 V is too small value of break-down voltage.

Active electrode (situated in electrolyte (2)) is made from activated carbon. Activated carbon is known for eminent porosity and a large surface of granulas. It is possible to extend electrod´s surface up to 200 m^2/g as a ply won´t be greater than 10 nm. In spite of small area carbon´s granula has a huge capacity (thousands F) close to small dimension – it leads to very low incoming electrode´s resistance, high gear of charging and discharging action. For example supercapacitor its parameters are 600 F/2.3 V and its dimensions are 4 x 6 x 9 cm and the weight is 290 g, has specific output hundred times greater than electrolytic capacitor.

Active carbon is compounded of aerogel. Aerogel is firm material where water was replaced by air. The next used materials are carbonic polymers. Carbonic nanotube are planned to use in future – surface of elements is greater.

A schematic detail of polarization is visible on *Fig. 3.*

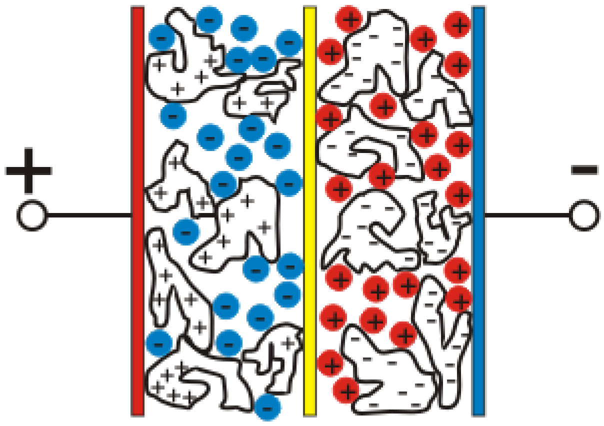

Fig.3.

2.2 *Supercapacitor battery*

Maximum voltage of supercapacitor depends on kind of used electrolyte. Maximum supercapacitor´s voltage is from 1,2 till 3 V. It is necessary to have capacitor battery with higher voltage than supercapacitor voltage. This problem is solved by series connection of supercapacitors whereas the capacitors capacity will be lowered. Because of different capacitors capacity is necessary to append capacitors of parallel resistors or voltage divider (bleeder resistor).

Serial-parallel connection is used in electric traction, capacitor´s capacity is about 60 - 80F, usage voltage is 600 V in routine.

2.3 *Supercapacitor accumulator used in electric traction*

Supercapacitor´s accumulator, except of supercapacitor, has other facilities provide storage and exhaustion energy from supercapacitor, provide protection of equipment and connection to contact line. A flow diagram is mentioned on picture *Fig. 4*.

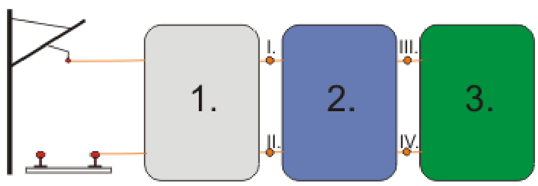

Fig. 4.

Supercapacitor accumulator can´t be compound only of single supercapacitor (Fig.4., block 3.). It is necessary to be semiconductor converter inside of supercapacitor accumulator which is able to operate in rising voltage mode – outflowing energy from supercapacitor and is able to operate in reducing mode for regulation of charging (Fig.4., block 2.). Charging and discharging duty of capacitor is limited by warming of supercapacitor cell.

Blocks 2. and 3. are completed of equipment network (Fig.4, block 1.) that provides connecting and disconnecting to contact line and switching off failure states of capacitor.

You can see circuit diagrams of separate blocks with description undermentioned.

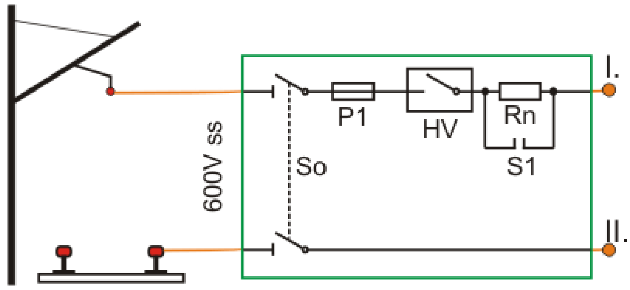

Fig.5. Input circuit (block 1., Fig. 4.)

So – Accumulator´s disconnector
P1 – Service fuse of power circuits
HV – Mains switch – DC high-speed breaker
Rn – Charging resistor – its function is reduce an electric current while is accumulator connecting to contact line (it limited charging current of filter capacitor C1- Fig. 6.)
S1 – Operating contactor to jump Rn

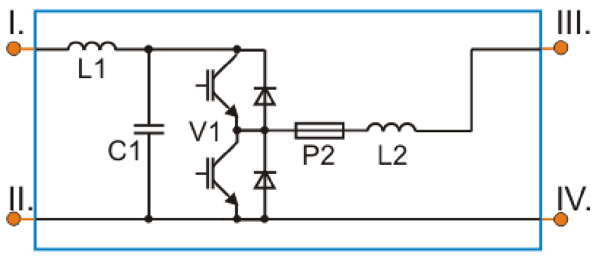

Fig.6. Voltage changer (block 2., Fig. 4.)

L1 – Filter inductor
C1 – Filter capacitor
V1 – Voltage changer – a block of IGBT transistors and diodes
P2 – Safety-fuse
L2 – Inductor to increase step-up operating of transducer

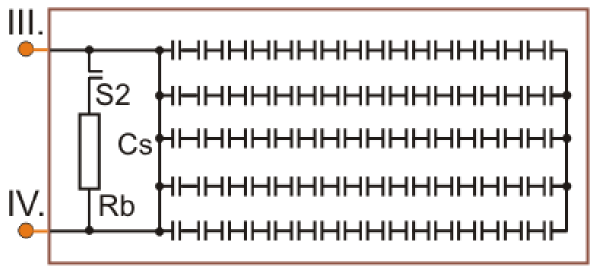

Fig.7. Supercapacitor battery (block 3., Fig. 4.)

S2 – Emergency contactor for discharging of capacitor battery
Rb – Discharging resistor to emergency discharging
Cs – Set of supercapacitors

CONCLUSION

Supercapacitor accumulator is the most suitable accumulator of recuperative energy for its technical simplicity and economically advantageous.

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