Improvement the Possibilities of Capacitive Energy Storage in Metro Railcar by Simulation

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***Abstract*—** This paper focuses on the use of modeling and simulation for one of the renewable energy.

The supercapacitors contribute to the rapid energy recovery associated with regenerative braking in electric vehicles. This power system allows the acceleration and deceleration of the vehicle with a lower loss of energy. Short-distance passenger traffic on electrified lines is a domain where brake energy recuperation might reduce the total energy consumption significantly. In this paper are presented the results of simulation models by Matlab-Simulink for an urban-metro railcar and some methods for reduce the need value of capacitance. The aim of the management of the energy storage system for improving performance is presented.

Keywords — : electric vehicle, regenerative braking, energy storage, supercapacitor, Matlab simulation.

I. INTRODUCTION

Reducing energy consumption is a priority to rail system operators. Regenerative braking was introduced in most countries to reduce energy consumption. This is only effective if other trains are available to use the regenerated energy. Regeneration also causes further voltage regulation issues, introducing voltage surges. Recent developments in energy storage devices, particularly supercapacitors and flywheels have made energy storage as viable technology to apply to railway systems. Energy storage devices can be used to tackle the issue of poor voltage regulation and help improve energy efficiency by storing regenerated energy from braking. This paper investigates the use of energy storage in mass transit systems, using Budapest Metro Railway as a theoretical case study. For improving the better use of the built energy storage devices some ideas and conceptions were investigated trough different way by a supposed energy management.

II. REGENERATIVE BRAKING

Regenerative braking generates electrical energy onto the overhead line. This energy can be used by other trains. By regenerating onto the overhead line, overall system efficiency gains can be made. For operational purposes, the overhead line voltage is limited; regenerated currents have to be control so that this limited is not exceeded. The effectiveness of regenerative braking is dependant on the receptivity of the system. If no other trains are motoring within the section, the regenerated energy cannot be used, and the energy has to be dissipated through resistor banks.

The issues associated with regenerative braking; particularly on DC systems can be avoided by using energy storage devices.

The energy storage devices can store regenerated energy on board trains or at the track side, hence reducing the magnitude of voltage swells too. On board stored energy provides an additional power source for acceleration, hence reducing the acceleration currents drawn from the overhead line and therefore reducing the magnitude of voltage sags.

III. POSSIBILITIES FOR ENERGY STORAGE

Supercapacitors are new components that can be used for short-duration energy storage. Its power density (W/kg) is similar for classical capacitor, but the stored energy density (Wh/kg) is much higher for supercapacitor. In comparison to standard batteries, the energy density of supercapacitor is lower by an average factor of 10, but their energy density is compatible with a large range of power applications that need high instantaneous power during short periods of time. These characteristics are typically found in transportation systems.

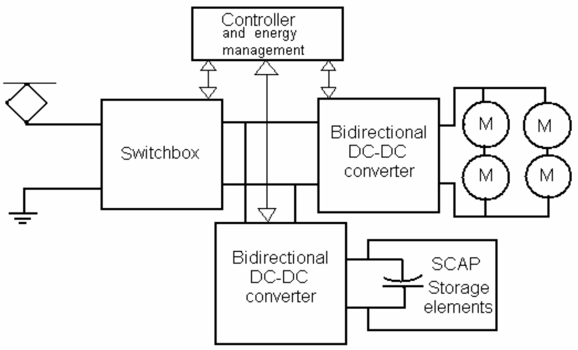

Figure 1. Railcar model

IV. ABOUT THE INVESTIGATIONS

The aim of this paper is to present how supercapacitive storage can be used for increasing the energy efficiency in a metro railway system. More train of railcars have DC drive via 4/4 operated converters. In this railcars yet can be imaginable a capacitive energy-storage device.

Main railcar characteristics are: weight w/o load 34 t, weight fully loaded 44 t, the DC motors power 4x50= 200 kW, the maximum speed 85 km/h and maximum acceleration more then 1 m/s^2, and the average distance is approximately 1000 m between stations.

The aim of the investigation is to determine the least needed capacitance value of the supercapacitor (C) for different conditions.

The base initial conditions were this: the distance between stations is 1200m, the mass one of the railcar is 40t, the speed maximum is 80km/h, the grade is 0 %o. In the Fig. 1 is shown the railcar model.

The Fig. 2 shows the direction of the simulation.

The first attained object was the value of the initial value of supercapacitor (C) voltage 840V, which we can calculate from the value of the capacitance C and the beforehand filled energy Ec_o into C for attain to this voltage. The maximum voltage of the grid is 900V. The least voltage through the discharge is select for 20 to 40 V what we set by tuning the variation of this “beforehand filled energy” E_{co} and the “constant filling power” P_{ct} through of the executives of the program Matlab-Simulink. Without the constant filling power P_{ct} it is need a significantly higher value of the C.

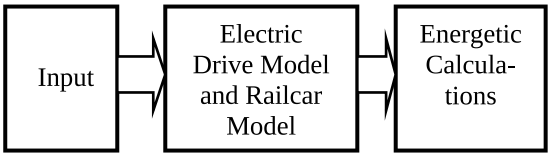

Figure 2. Aim and direction of simulation and calculations

This nature of this system was yet manifested at the beginning of the investigations through the executives.

The adequate degree of the constant filling-power P_{ct} is determined by the energy consumption of the motors, namely from the conditions of the transport and the parameters of the railcar. Accordingly the important aim of the investigation was to determine the adequate value of the constant filling-power P_{ct} and the least capacitance value for C.

The executives of the program were through two distances of the stations. The model calculated the energy consumption of the railcar and the diverse losses too.

The values of the motors energy consumption E_{mot} are plotted too on the figures where these values took into consideration the regenerated energy. Practically the energy consumption is divided by the running time given the approximate value of the constant filling-power P_{ct} that it was needed to tuning.

The benefits of the applications of the constant filling-power are:

-significantly lower need of capacitance,

-more equable load of the grid,

-the losses of the grid are lower on the motoring operation mode also.

The disadvantages are:

-its need to determine the estimated value of the constant filling-power in advance and to integrate the power of the motors and to compare these and if it is needed to correct those. All theses are been stored in the railcar controller and recallable.

-it must be controlled the DC-DC converter of the supercapacitor such the adequate value of the constant filling power must be realized together with the motoring operation. During the simulations we calculated the value of the filling power P_{ct} what was constant during an actual executive.

In this work the investigation is mainly theoretical so the value of the *d*

$$d=(Uc_{min} /Uc_{max})100 \tag{1}$$

is tolerated about 2-5%. In a real application this value of the *d* would be impermissible low.

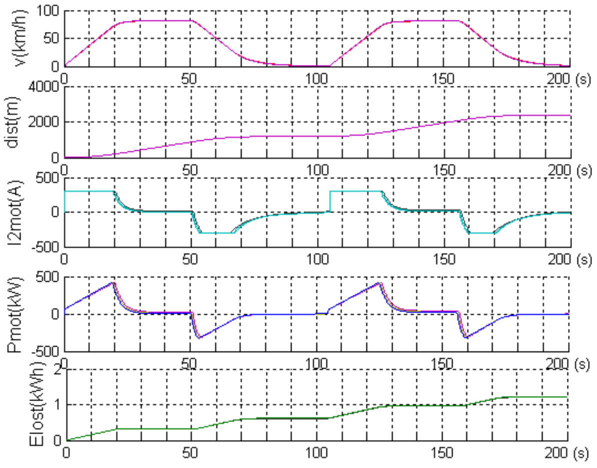

Figure 3. Speed, covered distance, motor currants, motor powers, energy losses v. time during two distance of between stations

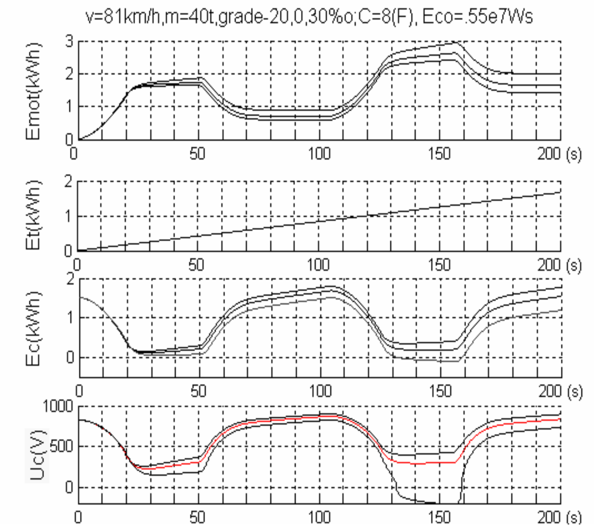

Figure 4. Motors energy consumption E_{mot}, constant filling power as filled energy E_t (if t=0 then E_t=Ec_o), energy of supercapacitor E_c, supercapacitor voltage U_c v. time

V. ANALYSES OF COURSES

The speed, the covered distance, the motor currants and the energy losses are shown on Fig. 3. The mass is 40t, grade are -20, 0, 30%o, distance on between station is 1200m, but on this two times 1200m done during in 200s. The effects of the grade differences for these curves are hardly visible.

In Fig. 4 shown is the same case as in figure 3.

Here are the energy level and voltage of supercapacitor (C). It is visible well that the end of the middle curve the grade 0 %o among three is as high as the curve of the

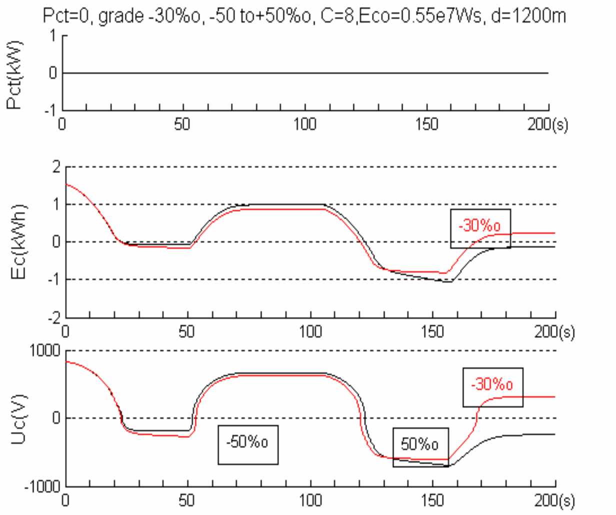

Figure 5. Without the constant filling-power P_{ct} the minimum value of the C is short

constant filling power in the end. This constant filling power here is yet insufficient for the case of 30%o grade. The voltage of C here is lower then 0 what is not possible in an electrolytic supercapacitor and is not allowable.

In Fig. 5 the curves are shown here for two distances between stations too. Without the constant filling-power P_{ct} the calculated and tried minimum value of the C is short.

The energy deficit at t=200 s to benchmark against the value of the beforehand filled energy Ec_0 are1.6 kWh and 1.9 kWh at this two cases of the grades, -30 és -50-+50%o. In the second case the grade is -50%o at first distance between stations and 50%o at one of the second.

If it would be permissible the change of the polarization of the supercapacitor C, in this case would run the curve of U_c as shown here and the values of the voltage C would be negative.

Sufficient value for the constant filling-power P_{ct} allows operating at minor value of the C. The energy management is manipulated by the controller, but its require for this the sizing of the C minimum in consideration of the prospective maximum values of the mass, speed, distance between stations and grades.

There is an important aspect by the setting of the P_{ct} providing for sufficient reserve capacitance in the supercapacitor-storage. The actual values of the P_{ct} are set by the controller by stored samples and the trends of the value energy level E_c and U_c respectively.

The samples may be recorded e.g. on some trial runs, or simulated fitting for an actual track in real-time way by the controller.

In Fig. 6 the values of the speed maximum are varied from 50 to 100km/h. Because of this at lower speeds the later points of the curves are slide on the time axis.

In Fig. 7 shown the minimum needed values in (F) of the supercapacitor capacitance C as two-variable function v.

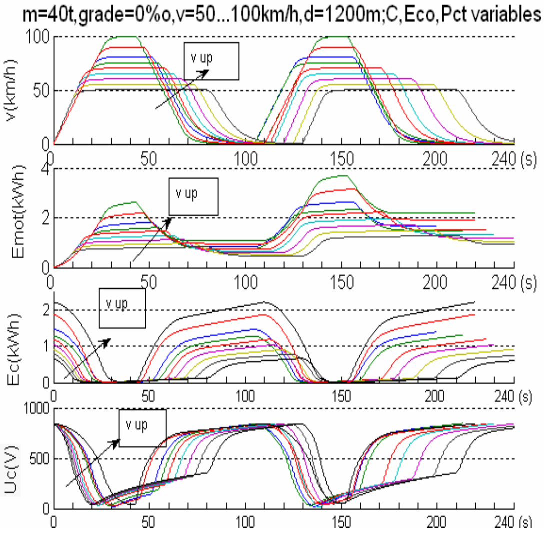

Figure 6. The speed is varied. Speed v, motors energy consumption E_{mot}, constant filling power as filled energy E_t (if t=0 then E_t=E_{co}), supercapacitor energy E_c, voltage U_c v. time

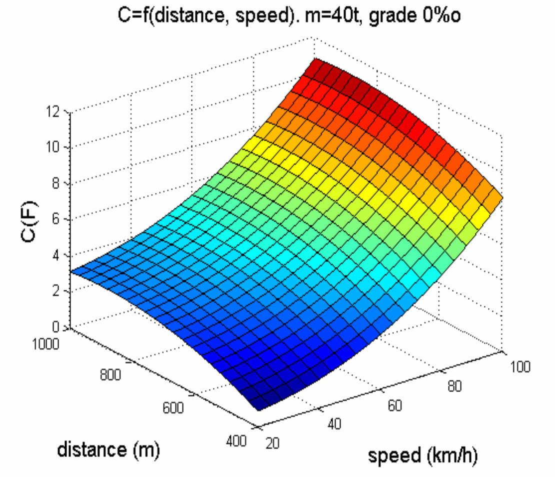

Figure 7. The minimum value of capacitance C=f(speed, distance)

. the speed (km/h) and distance between stations, (m):

$$C=f(speed, distance) \qquad (2)$$

This function is three-degree for the speed and two-degree for the distance. This two-variable function is fitted very good and controlled with least square method by Matlab:

$$C=Z = (5.5e\text{-}6*X^3+ 0.0011*X^2-0.0091*X+1.2251-2e\text{-}05*Y^2+0.0355*Y-10.7719)*0.5 \ \text{(F)} \qquad (2)$$

In Fig. 8 is shown the two-variable function of the constant filling power where

$$P_{ct}=f(speed, mass) \qquad (4)$$

In Fig. 9 and Fig. 10 are shown the two-variables functions of the constant filling power P_{ct} and the need initial values of Ec_0. The need initial values of Ec_0 in this function are

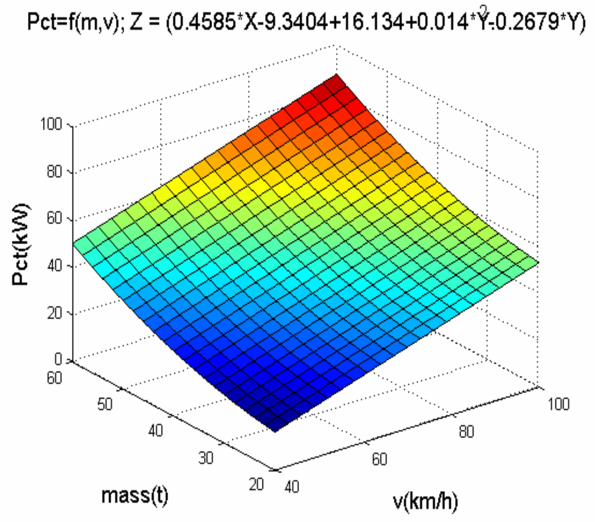

Figure 8. The constant filling power P_{ct}=f(speed, mass)

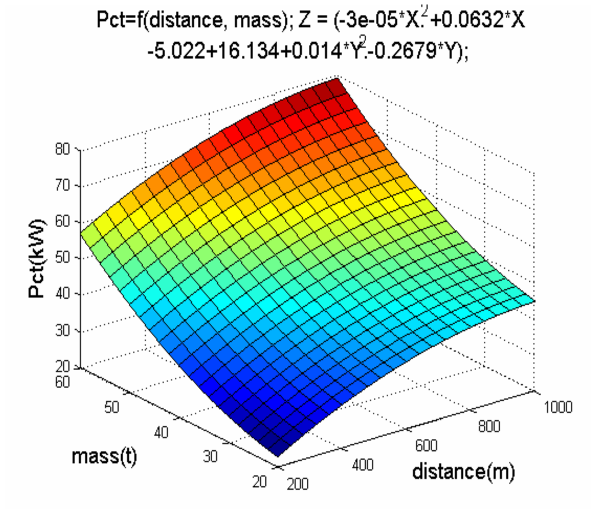

Figure 9. The need constant filling power P_{ct}=f(distance, mass)

$$Ec_0 = f(\text{mass, speed}) = 0.0119*X+0.0599+0.0003*Y^{1.6881}, \quad (5)$$

and

$$Ec_0 = f(\text{distance, speed}) = -2e\text{-}06*X^2+0.0026*X-0.4182+0.0119*Y+0.0599 \quad (6)$$

The effects of the distances to the functions are negligible if the distance is over 700m.

The size of the built-in C is given by the functions *C=f(distance, mass) and C=f(distance, speed)* from the transport task. With apply the value Ec_0 from the functions

$$Ec_0=f(\text{ mass, speed}) \text{ and } Ec_0=f(\text{distance, speed}) \quad (7,8)$$

we can give an initial voltage U_c=840V for the supercapacitor.

In Fig. 11 shown the energy saving in (%) v. speed, calculated from the energy consumption of motors, the electrical energy loss and regenerative energy.

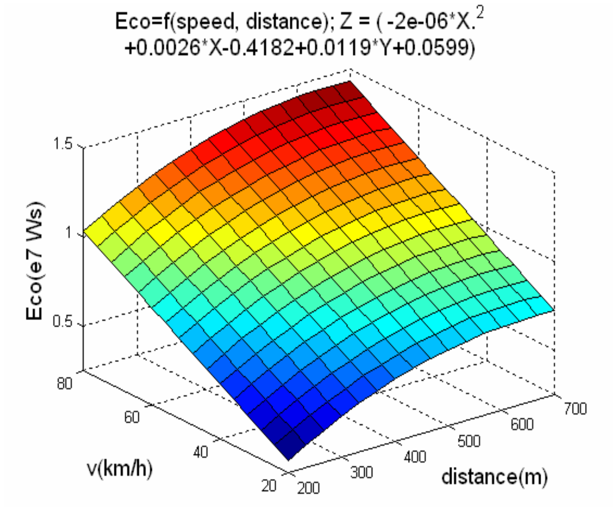

Figure 10. The need initial values of Ec_0=f(distance, speed)

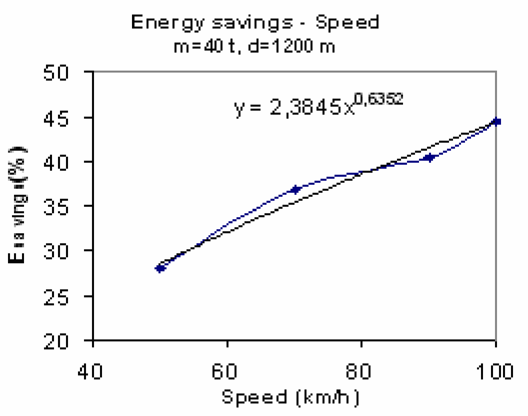

Figure 11. The energy saving v. speed function (m=40 t, distance = 1200 m, grade=0)

VI. RESULTS

In this paper we presented to determine the minimum need values in (F) of the supercapacitor capacitance C, the functions of the constant filling power P_{ct} and the need initial values of the beforehand filled energy in the supercapacitor Ec_0, and its polynomials which can facilitate to select the value of the capacitance C in case of the given conditions.

We presented the reason and the advantages of the beforehand filled energy (Ec_o) and the constant filling power (P_{ct}) applied in this simulation.

REFERENCES

[1]P. Barrade: Energy storage and application with supercapacitors. leiwww.**ep**fl.ch/**p**ublications/**barrade**_anae_03.**p**df

[2]P.Barrade, a. Rufer: High power fast energy exchange between storage system: supercapacitors as energy buffer in transportation systems. leiwww.epfl.ch/publications/destraz_barrade_**rufer**_pesc_04.pdf

[3]J.W. Dixon, M. Ortúzar, J. Moreno: Monitoring system for testing the performance of an electric vehicle using ultracapacitors. www2.ing.puc.cl/power/publications/electronics.ht**m** - 38k

[4]M. Chimera, A. Renfrew, M. Barnes: Energy storage devices in railway system. www.iee.org/oncomms/pn/**railway**/06innovation_chymera.pdf

[5]A. Rufer, P. Barrade: A supercapacitor based energy storage system for elevators with soft commutated interface. ieeex**p**lore.ieee.org/iel5/7586/20673/00955719.**p**df –

[6] I. Szenasy: Modeling and simulation for the energy storage by ultracapacitor in urban rail car. ECT 2008 Conf. Kaunas, Lithuania.

[7] I. Szenasy: Dynamic energy storages applications for metro railcars with computed simulation. Dissertation for Budapest Technical University, 1994 (in Hungarian).