A TRACTION DRIVE WITH A BATTERY AND ULTRACAPACITOR

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Introduction

This contribution describes a possibility to use an ultracapacitor in order to increase the efficiency of an electric drive with a traction accumulator. A 2-quadrant converter is used to connect the ultracapacitor into the DC link of the traction inverter (the accumulator). The elimination of heavy current peaks with both polarities is guaranteed by an appropriate control algorithm. This current peaks are caused by the main traction inverter during an acceleration from non zero starting speed or regenerative braking. An attention is paid to the energy and voltage relations. A suitable control structure is introduced.

Using the ultracapacitor the course of the battery current can be filtered to a long term average value without braking and accelerating peaks. Then the long-term RMS value of the current decreases and so the power loss on the internal resistance of the accumulator decreases too.

Moreover the lead-acid accumulator is not able to absorb the energy of regenerative braking if the braking starts immediately after a state when the current flowed from the battery (driving). This is caused by the time inertia of the chemical reactions in the accumulator. In this case a big part of the energy will not be stored to the battery but its charge will be even decreased like if the current had a opposite polarity. Using the ultracapacitor this negative effect is partly eliminated. So the trailing throttle of the vehicle and the life time of the accumulators can be increased.

Connection of the ultracapacitor to the battery

A parallel connection of the ultracapacitor to the battery is not suitable because it does not enable a higher voltage changing of the ultracapacitor. So a large amount of energy of the ultracapacitor can not be used. That is why a solution in fig.1 was designed. The 2-quadrant converter is able to transfer the energy in both directions between the accumulator (DC link of the traction inverter) and the ultracapacitor C_U.

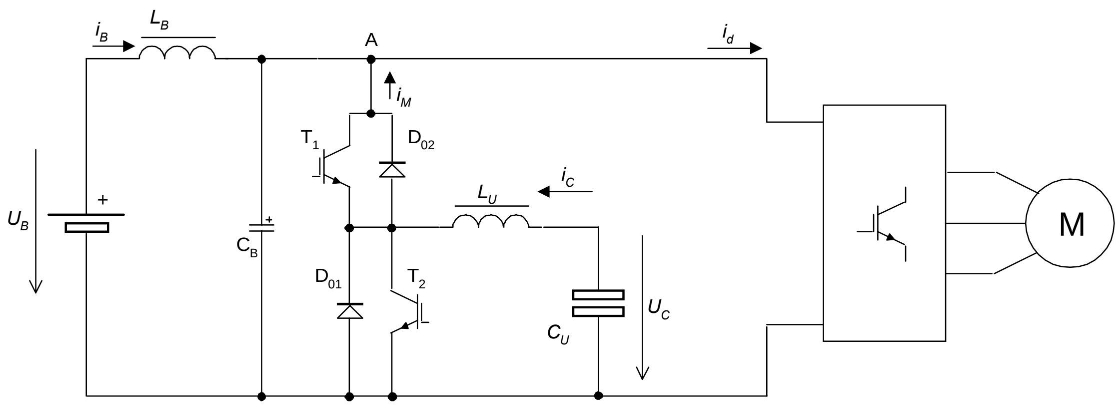

Fig. 1 *Connection of the ultracapacitor to the DC link*

Let´s suppose a condition that the voltage of the ultracapacitor U_U never decreases under one half of the accumulator voltage. This condition will be important because of the good efficiency of the converter. So the voltage of the ultracapacitor can vary in a range of $U_B/2$ to U_B. If it is $0{,}79U_B$ then the same energy ΔW can be stored or given out.

Values C_U = 10F a U_B = 550V will be used in an electric bus. Then it will be ΔW = 567 kJ. This represents for example a peak power of 100kW during 5,67s (acceleration or regenerative braking).

Control algorithm

The control circuit has to guarantee:

1) the elimination of the battery current peaks
2) setting the voltage of the ultracapacitor onto a demanded value

The priority ordered requirement is 1). The voltage of the ultracapacitor will be set only “long – termed”. The control structure uses a cascade control loops. The current loop controls the current of the ultracapacitor. The demanded current value of this loop consists of two additional parts. The first one is obtained from the battery current by a derivative element. The second one is taken through a rate limiter from an ultracapacitor´s voltage regulator. It is suitable to keep the voltage of the ultracapacitor inverse proportional to the speed of the vehicle (with respect to the condition of minimum value of $U_B/2$). So if the vehicle is standing the capacitor will be charged onto the full voltage in order to have energy enough for acceleration. At the maximum speed the voltage will be suitably decreased so the ultracapacitor can absorb the maximum energy.

The control system was simulated in MATLAB-SIMULINK-Power system blockset – see fig 2.

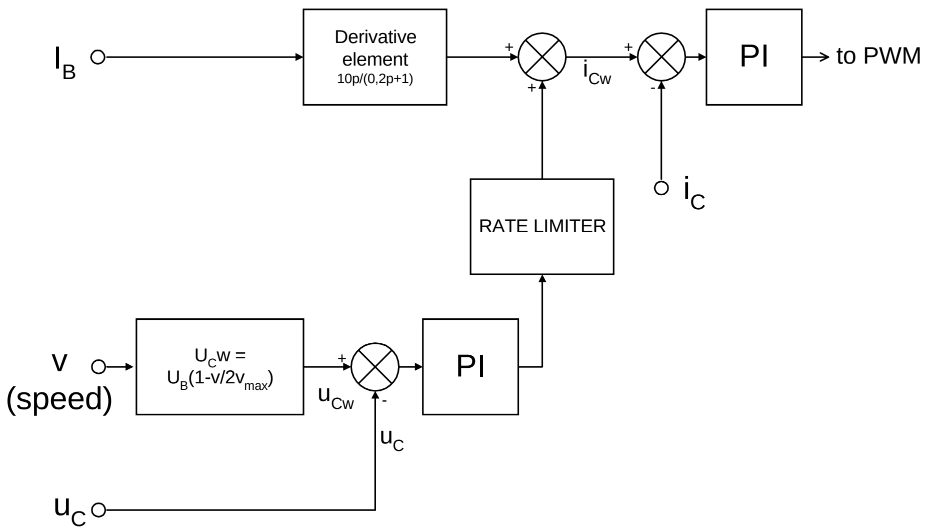

Fig. 2 *Simulation model of the electric scooter with an ultracapacitor*

The realization and verifying is done using an electric scooter constructed in our department. So the battery voltage of 48V and capacity of the ultracapacitor of 20F are used.

The maximum voltage of the ultracapacitor equals to the maximum battery voltage. In the case of our lead-acid traction accumulator 48V this voltage is about 58V – if the battery is fully charged and the scooter is just regeneratively braking. A higher voltage cannot appear because of overvoltage electronic protection which switches-off the transistors of the traction inverter or of the 2-quadrant converter.

Experimental results

The ultracapacitor is constructed as a serial connection of 30 cells 600F/2,3V (type B49300-G1605-Q fy Siemens Epcos).

A measurement of the capacity and current leakage of each cell was done to find out whether the cells can be serial connected without any overvoltage risk of some cells. If the maximum voltage of the whole capacitor is 58V then the voltage on each cell is 1,93V – in the case of capacity and current leakage symmetry. It was found out that the ratio of minimum and maximum capacity of the used cells each other is about 1,11. It is a sufficient result with respect to the number of cells and maximum allowed voltage.

Measuring the self-discharging of the cells the parallel leakage resistance of 7300Ω was found out. Resistors 120Ω connected parallel to each cell were used to avoid a negative influence of the leakage difference between the cells each other on the voltage distribution in the steady state. In these ways the uniform voltage distribution was guaranteed. Moreover LED diodes parallel connected to each cell were used to indicate an overvoltage of some cell in the case of some accident.

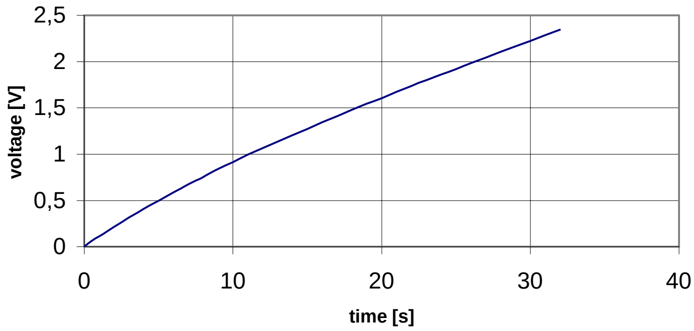

Fig.3 *The dependence of the cell voltage on the time during charging by a const. current 1A*

The capacity of the ultracapacitor depends on its voltage. This dependence can be deduced from the fig. 3 which shows the dependence of the capacitor voltage on the time during charging by a constant current. This is a non-linear curve. The cell capacity changes from 650F at zero voltage to about 800F at 2V.

Conclusions

The whole system is not fully finished yet. However the operation of the system was veryfied and it corresponds to the theory. The optimum gains and time constants of the controllers have to be set.

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