RESEARCH IN ELECTRIC TRANSPORT SUPERCAPACITOR ENERGY STORAGE SYSTEM

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Abstract. For increasing the power efficiency of electrical transport the on-board energy storage system can be used. In this article the applications of supercapacitor energy storage for regenerative energy saving in the vehicle braking mode and peak power shaping in the vehicle acceleration mode are described. The supercapacitor energy storage system practical operation is investigated on versatile DC motor test bench, which could be used for researching in various kinds of electric vehicle traction drives.

Keywords: supercapacitor, energy storage system, traction drive.

Introduction

One of the methods to increase the electrical transport energy efficiency is installation of on-board energy storage systems (ESS). It allows the vehicle regenerated braking energy saving for its subsequent use for the vehicle acceleration or its own needs [1-3].

In opposite to accumulator batteries, which are more intended as primary power supply source for long autonomous traction than regenerative braking energy storage, supercapacitors are more suitable for braking energy saving, and also for vehicle movement on limited distances that especially suits passenger electrical transport in case of movement on the disconnected site of a contact network or in case of substation power failure [4]. Use of supercapacitors also allows improving the dynamic characteristics of the vehicle. The fast charging possibility allows utilizing of supercapacitor battery for repeated peak power shaving to reduce traction drive starting torque drawn from power supply.

Such energy storage system is a relatively simple and efficient power saving device that could be installed practically on every vehicle independently from its primary power supply source: overhead network, internal combustion engine generator or accumulator battery. The installing of on-board supercapacitor energy storage system on the existing vehicle allows providing the limited autonomous traction mode without conventional power supply for short distances which improves the vehicle operation performance and reliability.

The choice of an optimum configuration and parameters of the system of stores requires a large number of experiments with vehicles that in itself is a power expensive action. Therefore, it is actual to apply the physical models of vehicles executed in a smaller power range. In this regard the configuration of the stationary DC traction drive test bench described in [5; 6] is presented in this paper.

However, for its development the computer model is necessary [7]. It allows choosing the necessary parameters of ESS without physical experiments that reduces the risk of the wrong choice of the equipment and, respectively, origins of emergency situations.

In the previous researches [5-8] various operating modes (acceleration, freewheeling, braking) of the electric vehicle with ESS at limited low speed range without application of the traction motor field weakening were considered, therefore in this paper the main attention is paid to operation of the traction drive at field weakening.

The applied results could be directly implemented to small power light electric vehicles or by help of physical simulation scaling factors introduced in heavy vehicles.

The principles of the traction drive test bench development

The schematic diagram of the traction drive test bench (TB) is shown in Fig. 1. The structure of the TB includes a model of the traction engine of the electric vehicle, a mechanical load simulator and energy storage system [5-9].

The model of the traction drive includes the DC motor M2 with a rated power 3.7 kW and rated speed 1370 rpm and DC/DC converters. The DC/DC converter [5; 7] includes the switches VT2 and VT3, a choke coil L2 and capacitor C2. The excitation winding L_f is connected to the independent converter (switch VT5 and diode VD3). The converters are connected to the 110 VDC bus. The traction drive is equipped with the braking circuit consisting of a switch VT4, diode VD2 and the braking resistor $R_{br,dc}$. The function of this circuit is dissipation of the braking energy in that case when charging of ESS is impossible.

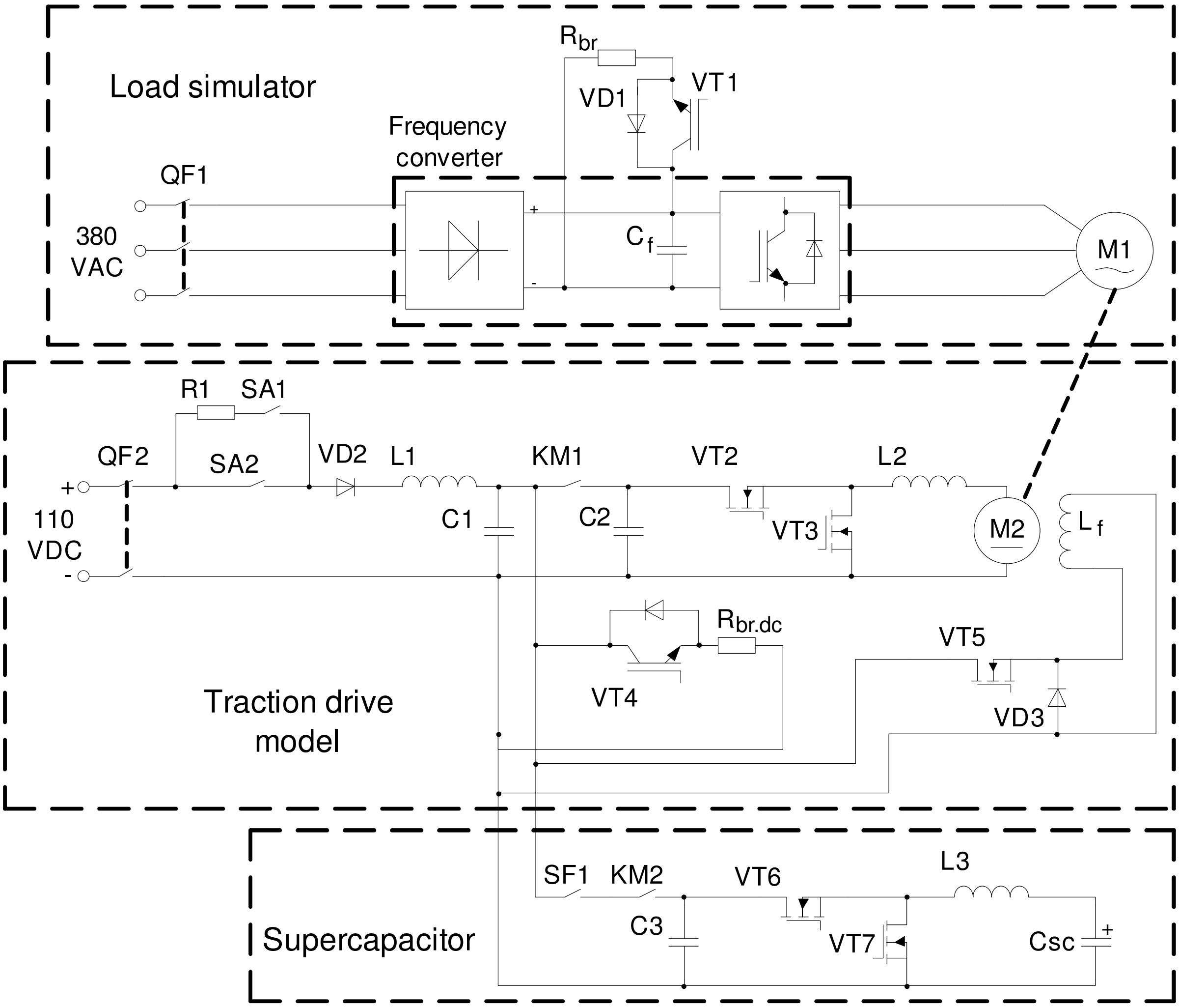

Fig. 1. **Schematics of the traction drive test bench with supercapacitor energy storage system**

The energy storage system includes the Maxwell BMOD0063-P125 supercapacitor with a capacity of 63 F and maximum voltage 125 VDC. The supercapacitor is connected to the 110 VDC bus through the DC/DC converter.

The load simulator [9] consists of the AC motor M1 with a rated voltage 380VAC/50Hz, rated power 4 kW, rated speed 1450 rpm and the frequency converter Danfoss VLT5022. The frequency converter uncontrollable input diode bridge rectifier makes impossible the return of the braking energy of the AC motor in a network, therefore for its dissipation the braking resistor R_{br} is used.

In TB the DC motor with independent excitation is used to simulate the characteristics of the DC machine with series excitation.

The computer model of the test bench

The Matlab/Simulink model (Fig. 2.) of the test bench was in [7] described. The controlled current source and the diode D1 simulate the contact network substation where the resistance R1 is equivalent to the active resistance of the contact line wires.

The voltage limiter on the DC bus is realized, using a voltage source V2 and the diode D3. The signal builders *I_ref* and *V_sub* are used respectively for a reference current of the traction motor and substation voltage that allows to simulate various operating modes (accelerating/braking, power failures).

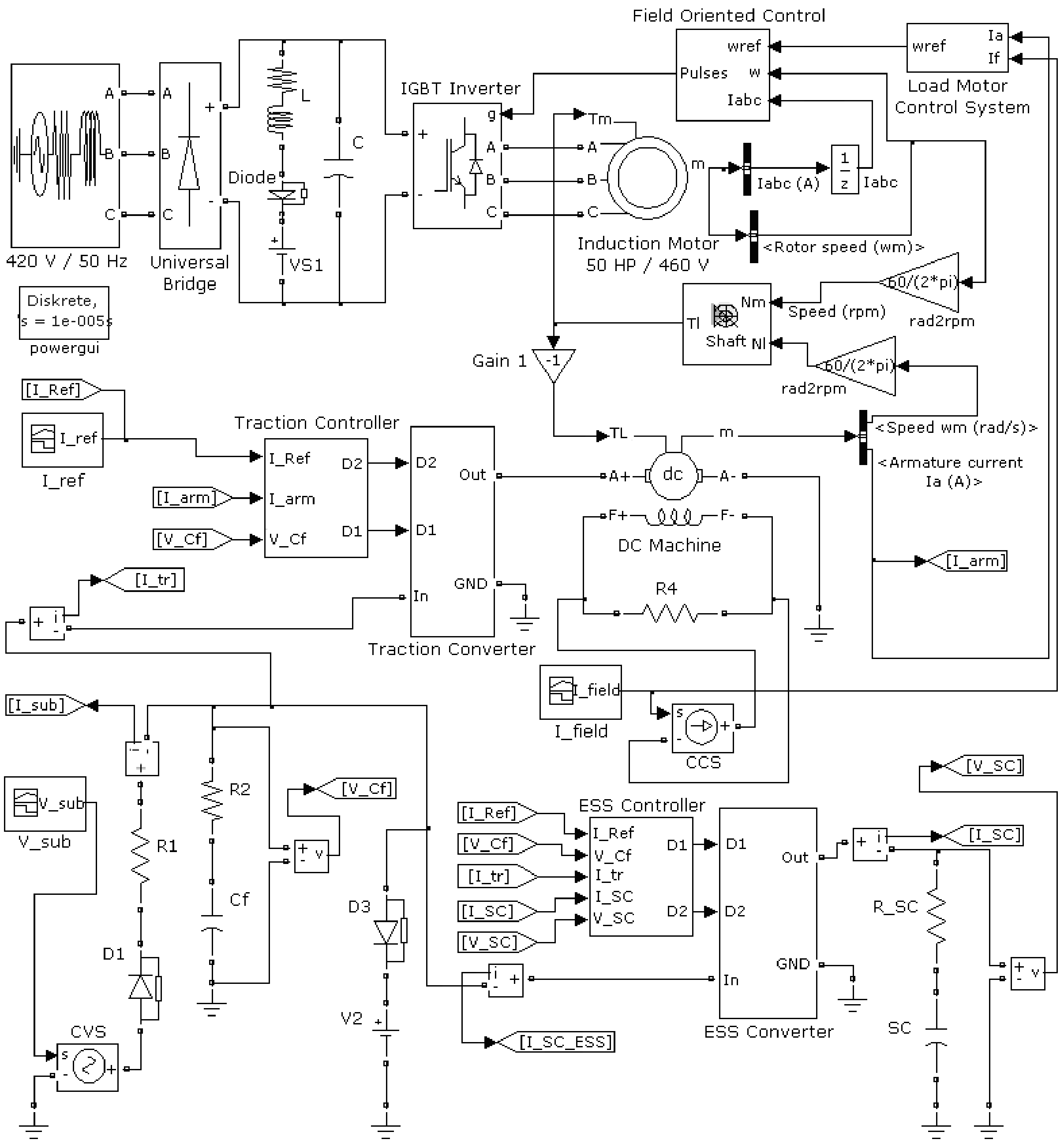

Fig. 2. **Simplified Matlab/Simulink model of the traction drive test bench**

Within this paper operation of the test bench with field weakening of the traction motor is investigated. For this purpose in the model the excitation current source is replaced by the controlled current source and signal builder *I_field*.

Simulation results

The Matlab/Simulink model has been approved for simulation of full loaded T3MR tram with the mass 30.2 t. The calculated test bench power scale factor $K_P = 85.5$, the speed scale factor $k_n = 1.255$. The simulated diagrams at 30 s acceleration with maximum current 40.5 A, 2 s freewheeling and the following braking are shown in Fig. 3 and Fig. 4.

In difference from the tram with two levels of a field weakening, in simulation only one field weakening stage 55 % is used at acceleration and one – 30 % at braking mode. Excitation current is thus regulated non-uniformly. In Fig. 3 the diagram corresponding to a right choice of the excitation current value according to the traction motor speed curve is shown.

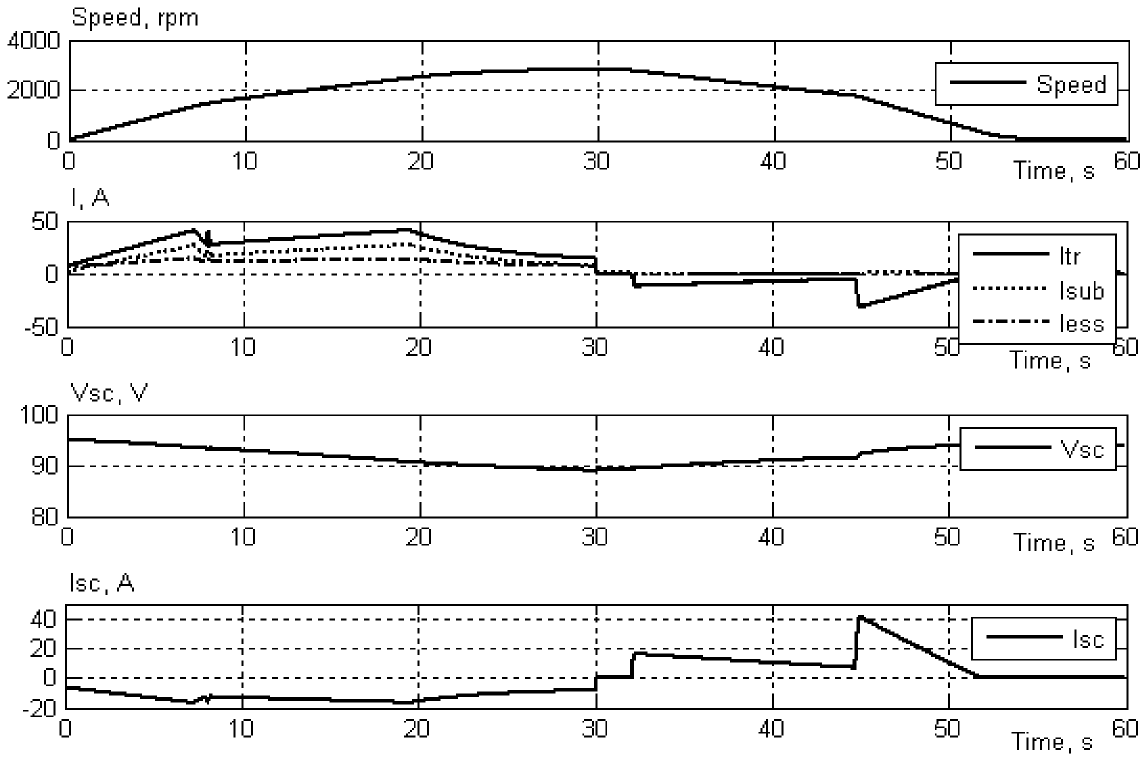

Fig. 3. **Simulation diagram at correct choice of excitation current value:** Itr – traction current; Isub – substation current; Iess – ESS current; Iref – armature current reference; Iarm – armature current; Vsc – supercapacitor voltage; Isc – supercapacitor current

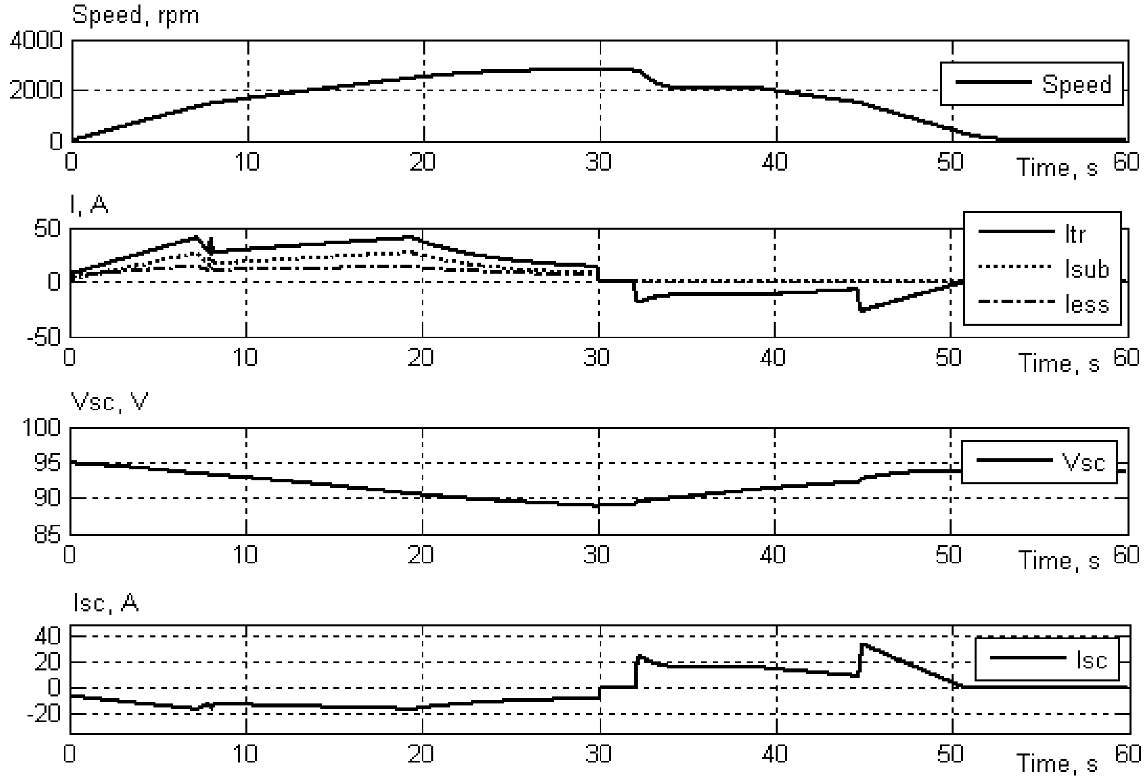

Fig. 4. **Simulation diagram at incorrect choice of excitation current value:** Itr – traction current; Isub – substation current; Iess – ESS current; Iref – armature current reference; Iarm – armature current; Vsc – supercapacitor voltage; Isc – supercapacitor current

If the choice of the excitation field level is carried out incorrectly, the speed curve takes a form, as in Fig. 4. In this case the motor in braking mode sharply dumps the speed to 2000 rpm (32-34 s).

The comparison of the traction drive operation at different field weakening levels must be realized at identical other parameters. In this case invariable there are armature current reference, supercapacitor voltage working range and its initial voltage. On the diagrams given below the initial voltage of the supercapacitor is equal to 95 V.

From the supercapacitor current curve in Fig. 3 it can be concluded that by using of independent excitation DC motor only approximate simulation is possible of series excitation DC traction motor behavior. In this computer simulation the ballast resistor was not used because of irrationality and inefficiency of such solution use in the test bench.

Conclusions

1. Use of independent excitation DC motor allows carrying out approximate simulation of the series excitation traction DC motor behavior. Correct simulation depends on fine tuning of the field weakening level. In other cases at 32-34 seconds sharp speed falling is observed.
2. The most precise results are received at the ESS supercapacitor initial voltage 95 V.
3. Fore more precise series excitation DC traction motor simulation on the test bench, only stepless field weakening system that automatically keeps traction motor field excitation current below 0.33 A at high motor speeds above 1370 rpm when motor voltage exceeds 110 V.
4. Use of the ballast resistor in the test bench is irrational due to additional energy losses, and in the computer model it was not used, too.

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