

Investigation of the supercapacitor mathematical model by means of LTspice IV

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Abstract – In this paper the supercapacitor mathematical model was researched by means of the Linear Technology SPICE simulator.

Keywords – Supercapacitor mathematical model, equivalent circuit, analog circuit simulation, electrical parameters.

I. INTRODUCTION

The supercapacitors are passive electrostatic energy storage device that are composed of complementary porous carbon electrodes immersed in an organic electrolyte and are capable of fast charge/discharge [1]. These advantageous properties of the supercapacitors make them suitable for use in many applications such as in hybrid-electric vehicles, military applications and telecommunications systems [2].

Since the equivalent series resistance (ESR) in supercapacitors is extremely low, an supercapacitor can be charged with a very high current; this is not possible in energy storage devices like batteries that have higher ESR, because in those devices current must be limited to avoid overheating. In addition, no chemical reactions are involved in the storage and release of energy from ultracapacitors. This means that charging and discharging can be done with the same high rated current.

In high current drain applications, the supercapacitor will be subjected to a highly dynamic performance behavior which efficiency is of primary concern. It is important to be able to predict the dynamic behavior of the supercapacitor under various environmental constraints over short periods. In this paper we evaluate the performance of the supercapacitor during the impulse operation by means of the Linear Technology SPICE simulator (LTspice IV).

The development of a suitably accurate high-order model of the ultracapacitor cell can:

- accurately predict the terminal voltage under different current profiles;
- more closely model the slow transient due to charge redistribution to better account for true stored charge and to calculate the instantaneous power available;
- allow for a more sophisticated energy storage system control strategy;
- improve pack balancing strategies;
- extend the voltage operating range in some particular cases.

II. SUPERCAPACITOR SPICE MODEL

Ideally, the mathematical model for the supercapacitor should be based on its physical structure. In [3, 4], the authors presented the supercapacitor equivalent circuit that is based on the activated carbon electrode structure. The

supercapacitor equivalent circuit for the one branch of the porous electrode is shown in Fig. 1.

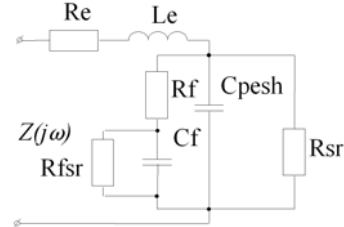


Fig.1 One branch of the porous electrode equivalent circuit

The one branch of the porous electrode equivalent circuit consists of next elements: Re is the active specific electrode resistance, Le is the active specific electrode inductance, Rf is the active specific electrolyte resistance, Cpesh is the specific capacitance of the large diameter pores (fast capacitance), Cf is the specific capacitance of the small diameter pores (slow capacitance), Rfsr is the active specific self discharge conductance of the small diameter pores (slow conductance) and Rsr is the active specific self discharge conductance of the large diameter pores (fast conductance).

The activated carbon electrode input impedance can be written as equation Eq.1.

$$Z(j\omega) = \left[\frac{Re + j\omega Le}{\left(R_f + \frac{1}{\frac{1}{R_{fsr}} + j\omega Cf} \right) + \frac{1}{R_{sr}} + j\omega C_{pesh}} \right] \times \left[(Re + j\omega Le) \cdot \left(\frac{1}{R_f + \frac{1}{\frac{1}{R_{fsr}} + j\omega Cf}} + \frac{1}{R_{sr}} + j\omega C_{pesh} \right) \right] \quad (1)$$

The supercapacitor SPICE model also includes the voltage source B1 and the voltage source equivalent resistance Rv. The supercapacitor SPICE model is shown in Fig. 2 and simulated in the Linear Technology SPICE simulator (LTspice IV). The main features of the supercapacitor SPICE model are the nonlinear resistances Re, Rfsr that simulate nonlinear electrochemical process in the supercapacitor.

The source B1 is the arbitrary behavioral voltage source that allows to set the different simulating monitoring signal by means of the function V=F(...). This function can define the alternating voltage monitoring signal or the direct voltage level for the supercapacitor simulation.

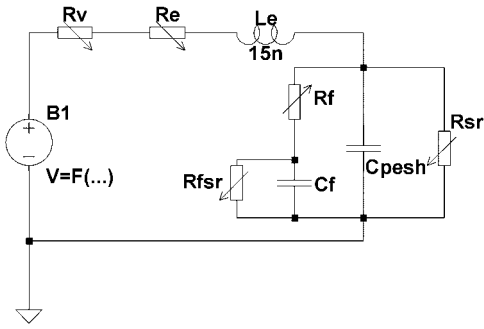


Fig.2 Supercapacitor SPICE model

By using of the supercapacitor SPICE model the various simulations were performed for example the simulated impulses that pass through the supercapacitor are shown in Fig. 3.

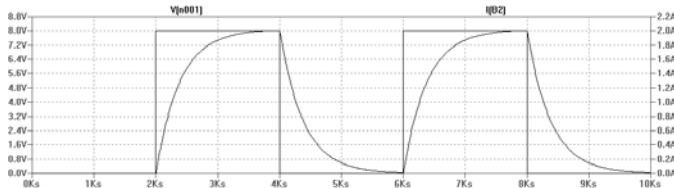


Fig.3 Supercapacitor pulses

By using of the supercapacitor SPICE model the direct pulse generator of ultra wideband radars with using of the supercapacitors was simulated. The block diagram the direct pulse generator of ultra wideband radars with of the using supercapacitors is shown in Fig. 4.

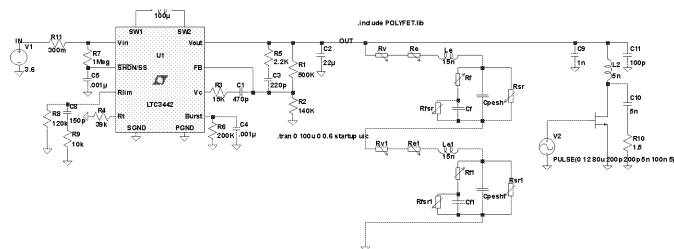


Fig.4 The block diagram of the direct pulse generator of ultra wideband radars using of the supercapacitors

By using of the direct pulse generator SPICE model with the supercapacitors the current impulses that pass through supercapacitors were obtained and shown in Fig. 5.

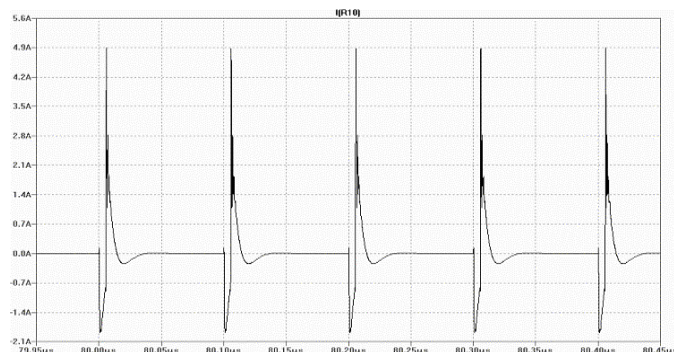


Fig.5 Current impulses in the direct pulse generator SPICE model

The simulation results allow estimating the increasing of the impulse amplitude and power at using of the supercapacitor block in the direct pulse generator of ultra wideband radars. The power-increasing coefficient of the output signal is calculated by expression (2).

$$m_p = \frac{P_2}{P_1} = 2,56 \quad (2)$$

By using of the simulation results the impulse front decreasing coefficient for the direct pulse generator was obtained as shown by expression (3).

$$m_i = \frac{\tau_{f1}}{\tau_{f2}} \approx 1,26 \quad (3)$$

The current impulse shape of the direct pulse generator output signal is shown in Fig.6.

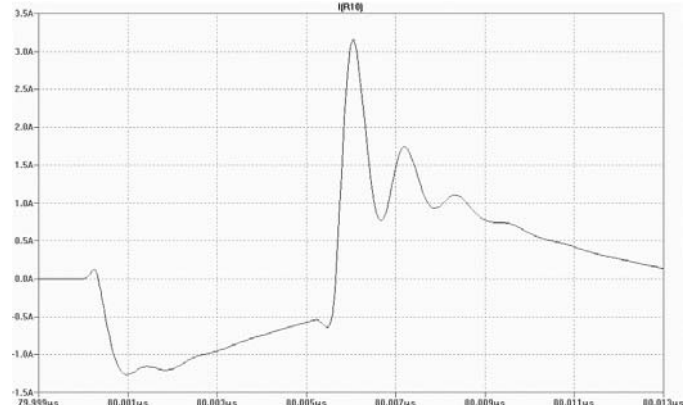


Fig.6 Current impulse shape of direct pulse generator output signal

III. CONCLUSION

1. In order to validate the behavioral model for the supercapacitor, implementation and simulating of the operational characteristics including the terminal voltage, output power, and energy delivered under various load conditions, equations which describes the various characteristics of the supercapacitor were entered into the Linear Technology SPICE simulator (LTspice IV) and compared to the experimental results. The simulated terminal voltage under pulse current load shows good agreement with the terminal voltage from the experiment.

2. The performed supercapacitor simulation allows researching the supercapacitor current impulses for various operation modes. The simulation results are coincided with experimental results conducted by means of the special measurement system.

3. Because of the large improvement in power performance of the supercapacitors the emergence for new and diverse applications has improved significantly. The optimum energy-power performance for the supercapacitors can be efficiently determined using computer simulation.

4. An equivalent circuit model for supercapacitors was obtained from the impedance spectra and simulated in Linear

Technology SPICE simulator (LTspice IV). The result shows that accurate simulation of the terminal voltage under dynamic load current and constant power load can be achieved. We have shown that the optimum operating conditions between specific power and specific energy can be determined from simulation.

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