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Modelling a Charging Process of a Supercapacitor in MATLAB/Simulink for Electric Vehicles

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Abstract. To control a smart grid in stationary application or in an embedded application such as electric vehicles, it is needful to comprehend behavior and modelling of the energy storage devices. In this article a simple electrical model for describing charging process of a supercapacitor for usage in electric vehicles applications is depict. Three scenarios with three equivalent scheme are proposed. The studied models are realized in the MATLAB/Simulink environment. The models and the simulation results of the supercapacitor are compared and analyzed.

INTRODUCTION

Nowadays, the energy storage devices are increasing in utilization in many applications such as electric and hybrid vehicles, micro and nanogrids. The supercapacitors (SC) are characterized by multiple aspects such as long cycle life, short charging time, low resistance which enables high load currents, excellent low-temperature charging and discharging processes and higher power density [1-3]. These characteristics makes them appropriate for delivering and absorbing higher current in short time periods which could be suitable for applications such as regenerative braking and acceleration conditions in electric vehicles. In comparison with the other energy storage devices used in electric and hybrid vehicles such as battery banks, flywheels and fuel cells, their productivity depends on their aging stage.

The supercapacitors are exposed to multiple negative influences such as low specific energy, aging under temperature effects, charge/discharge cycles of high current intensities and so on [10, 11].

MODELLING OF THE SUPERCAPACITOR

Supercapacitor Model Structure

The most frequently used methodology for describing the operations modes of a supercapacitors is R-C model [9]. This equivalent circuit is presented and it is composed by resistance R (frequently called equivalent serial resistance-ESR) and capacitance C. In this research three models of supercapacitors with one, two and five branches are presented respectively on Figure 1 to 3.The studied models are used for a representation of the behavior of the supercapacitor and its storage capacitance.

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The major advantage of the presented solution is the possibility to conduct the test for charging or discharging of the supercapacitor. These researches are accomplished at condition that the current is constant. This test is presented by European Standard [12].

The usage of the supercapacitor in EVs is preferred due to the multiple advantages. In the following Table 1 a comparison of the characteristics of the supercapacitor and the battery for usage in EVs are described.

TABLE 1. Comparison between supercapacitor and batteries

Function	Supercapacitor	Lithium-ion (general)
Charge time	1–10 seconds	10–60 minutes
Cycle life	1 million or 30,000h	500 and higher
Cell voltage	2.3 to 2.75V	3.6V nominal
Specific energy (Wh/kg)	5 (typical)	120–240
Specific power (W/kg)	Up to 10,000	1,000–3,000
Cost per kWh	$10,000 (typical)	$250–$1,000 (large system)
Service life (industrial)	10-15 years	5 to 10 years
Charge temperature	–40 to 65°C	0 to 45°C
Discharge temperature Row	–40 to 65°C	–20 to 60°C

Scenario 1

In Scenario 1 an equivalent circuit with one R-C branch of the supercapacitor is presented. The supercapacitor, initially discharged, is charged by applying a constant current ic until the voltage reaches its rated value Ud. Then the supercapacitor voltage is regulated at Ud.

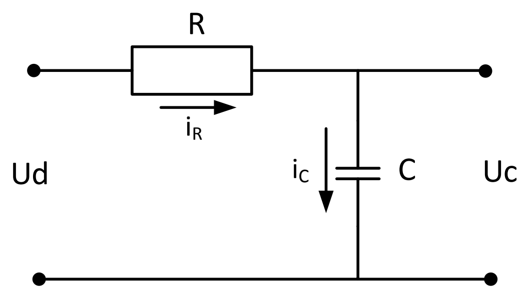

FIGURE 1. Equivalent circuit of one branch R-C model of a supercapacitor

The following equations describe the operations of the proposed equivalent scheme on Fig. 1:

$$U_d = i_C R + U_c \tag{1}$$

$$i_C = \frac{1}{C}\int U_C dt \tag{2}$$

where U_d is the input voltage, R is the series resistance, C is the capacitance of the capacitor, U_C is the voltage of the capacitor.

Scenario 2

The three RC branch models presented in this paper are results from models [1]. In scenario 2 an electrical circuit is composed of two RC branches and presented on Figure 2. The first branch represents the processes of charging or discharging. The second branch represents the process of charge redistribution, which is observed after a charge or a discharge when the current equals zero.

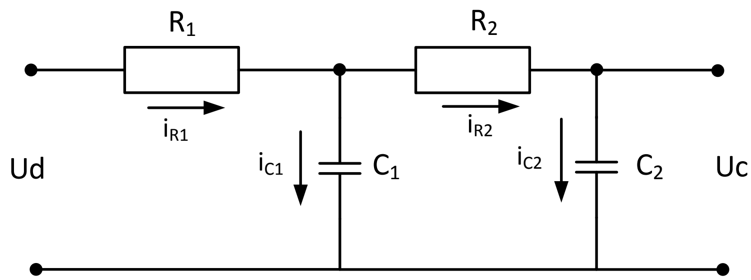

FIGURE 2. Equivalent circuit for two-branch ladder R-C model of a supercapacitor

The following equations describe the operations of the proposed equivalent scheme on Fig. 2:

$$U_d = i_{R1} R + U_{C1} \tag{3}$$

$$i_{C1} = \frac{1}{C_1} \int U_{C1} dt \tag{4}$$

$$i_{R1} = i_{R2} - i_{C1} \tag{5}$$

$$U_{C1} = i_{R2} R_2 + U_{C2} \tag{6}$$

Scenario 3

To research the physical structure leading to the relationship between the delivered charge and the discharge, a simple RC ladder circuit model for supercapacitors is analyzed and presented on Figure 3. The studied model is consist of five RC branches to describe the processes of the supercapacitor. The input voltage of the system is denoted as U_d and the supercapacitor voltage is denoted as U_C. During a charging process, the source or load is applied to the supercapacitor terminals and the capacitor of each RC branch is accessed through a series connection of all resistors from the supercapacitor terminals to the branch in question.

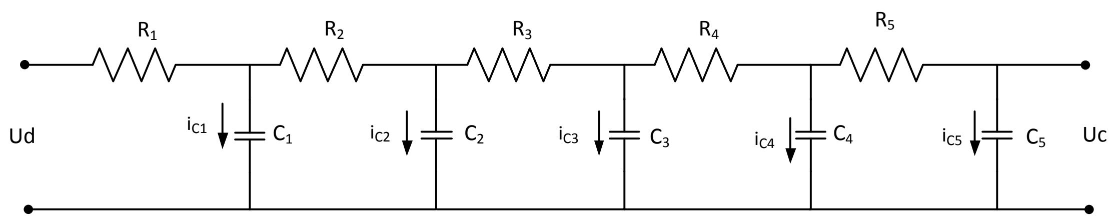

FIGURE 3. Equivalent circuit for five-branch ladder R-C model of a supercapacitor

For the scheme of Figure 3, analogous ratios are valid, as in Figure 2.

Model of the Studied System in MATLAB/Simulink

On Figure 4 a block diagram of the studied system is presented. The developed system is composed by a grid, filter, AC/DC converter with power factor correction (PFC), a DC/DC converter and a supercapacitor with battery management system (BMS). The usage of a rectifier with power factor correction is necessary to improve the power factor and also power quality with the help of the capacitors. The PFC systems increase significantly the efficiency of the entire system.

A key element in the electric vehicles energy storage devices is the BMS. This system executes a multiple functions concerning SC bank such as protection of the system from damage, prediction and increasing of the life cycle.

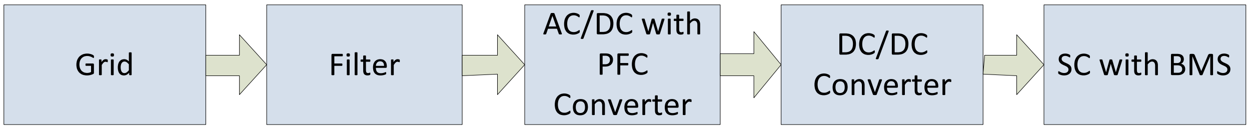

FIGURE 4. Block diagram

On Figure 5 a scheme of the studied system is presented. This system is composed by a controller, power converter and a supercapacitor.

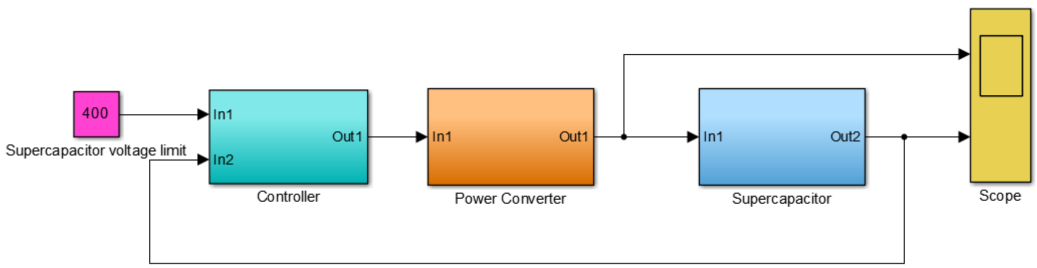

FIGURE 5. A scheme of the studied system in MATLAB/Simulink

SIMULATION RESULTS

On Figure 6, Figure 7 and Figure 8 simulation results of the current and the voltage of the studied supercapacitor are presented. It is observed that the set value of the current (200 A) under different initial conditions of the voltage of the capacitor, different charging times are obtained. The voltage is limited to 60 V for application in EVs.

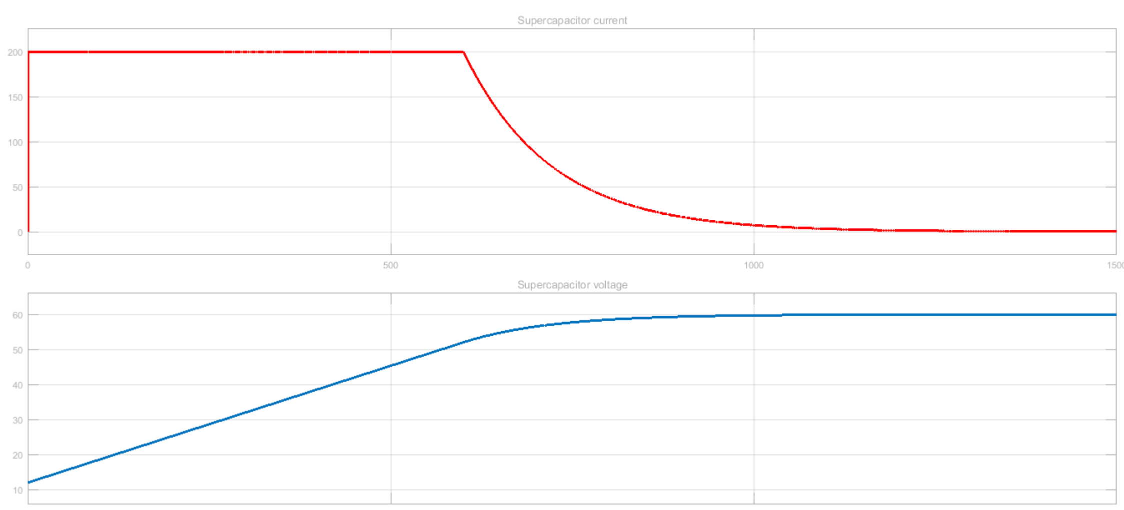

FIGURE 6. Supercapacitor current and voltage for Scenario 1

A capacitor with a capacity of 3000F and a starting voltage of 12V was used.

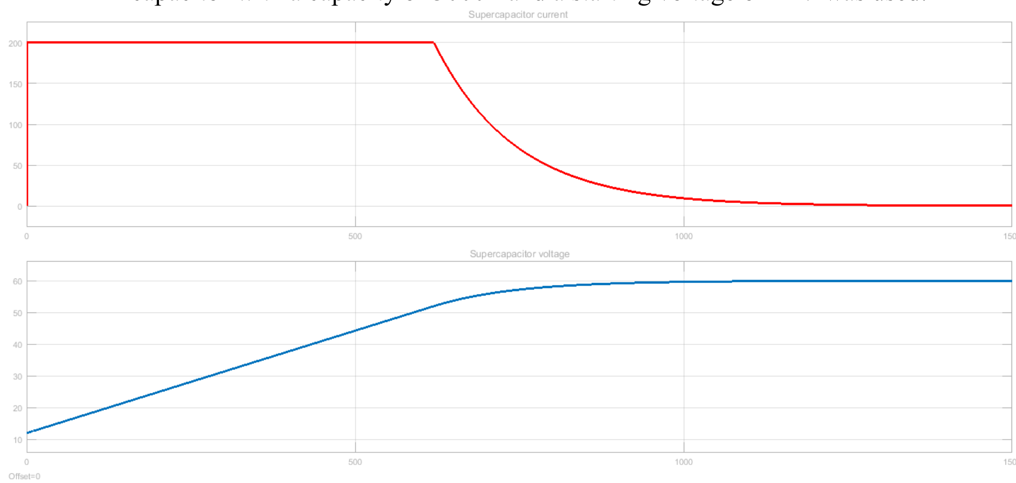

FIGURE 7. Supercapacitor current and voltage for Scenario 2

Of the results shows that the capacitor is charged for about 1000 seconds at this initial voltage value.

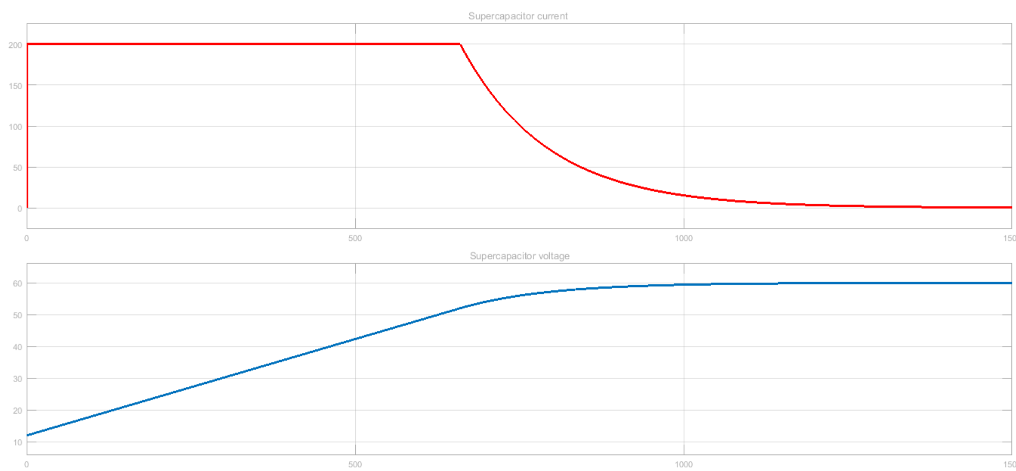

FIGURE 8. Supercapacitor current and voltage for Scenario 3

In modeling the charging process used averaged models of power electronic converters. This allows working with long times of simulations in the order of minutes and hours. By modeling of different scenarios uses model parameters of the elements given in [4, 5, 7, 15, 17].

By comparing the results of simulations with different equivalent circuits, it can be seen that in the modeling of long duration processes, such as the charge processes, there is no noticeable difference in behavior. Thus modeling the charging process should be used simplified models.

CONCLUSION

In the current research a charging model of a supercapacitor for usage in electric vehicles application is examined. Several scenarios of a classical R-C model of a supercapacitor are proposed. From the examined research it is observed that the model is suitable for application in electric vehicles. The studied model is realized in MATLAB/Simulink software environment.

As a result of numerical experiments, it has been found that the complexity of the superconductor models does not have a direct effect on the shape and nature of the charge process. On the other hand, the use of detailed models is justified in other studies - eg aging, temperature behavior, self-discharge, and so on.

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