Modelling of DC-DC Converter for Charging of Energy Storage Devices

Gergana Vacheva
Department of Power electronics
Technical University of Sofia
Sofia, Bulgaria
gergana_vacheva@tu-sofia.bg

Nikolay Hinov
Department of Power electronics
Technical University of Sofia
Sofia, Bulgaria
hinov@tu-sofia.bg

***Abstract*—In the current research a mathematical model of DC-DC converter charging an energy storage devices is presented. The model of the converter is realized in MATLAB/Simulink. For energy storage devices is used a supercapacitor.**

***Keywords*—DC-DC converter, energy storage, supercapacitor.**

I. INTRODUCTION

The use of an energy storage system is often necessary for energy storage applications. The storage component is used:

- in isolated systems where it supplies devices requiring reduced energy

- in hybrid systems where it plays a role in terms of power supply or energy depending on the application (eg. acceleration or braking phases).

Until now, the most used systems are accumulators which have a specific power and relatively high autonomy. Conventional capacitors have insufficient autonomy, but have incomparable specific power. The supercapacitors appear to be intermediate components in terms of energetic properties that make them very interesting because they have practically no competitors in this field.

The first supercapacitors had a high series resistance, which induced a average efficiency and limited specific power. In recent years, we have witnessed a very great effort on the part of manufacturers to reduce internal resistance, increase the storage capacity, as well as the nominal operating voltage. The following table 1 gives the illustration of the evolution of the performance of supercapacitors[1].

TABLE I. CHARACTERISTIC OF MAXWELL SUPERCAPACITOR

Nominal voltage [V]	Capacitance [F]	Volume [L]	Series resistance [mΩ]	Specific power [kW/kg]	Specific energy [Wh/kg]	Current [A]
2.3	100	0.031	8	4.5	2.0	30
	600	0.183	2	2.3	1.5	300
	1800	0.26	0.4	10.7	4.5	–
	2300	0.59	0.5	3.6	2.3	400
	2700	0.60	0.6	3.0	2.7	400
	3600	0.59	0.59	1.7	4.1	200
2.5	200	0.047	1.8	16	3.2	50
	600	0.14	0.6	18	3.3	300
	1200	0.23	0.4	13	3.5	300
	2700	0.52	0.23	11.3	3.9	500
	3600	0.64	0.2	11.2	4.5	500
	5000	0.80	0.25	7.4	5.1	500
2.7	2600	0.36	0.28	4.1	5.6	500

Electrochemical batteries, known only as "batteries", are electrochemical devices that convert electrical energy into potential chemical energy during charge and vice versa during discharge. The battery consists of several cells put together. Basically, a battery cell consists of three components: two electrodes (positive and negative) immersed in an electrolyte.

Battery manufacturers usually categorize them with coulometric capacity (ampere-hour). Another important parameter of the battery is the state of charge (SoC). It is defined as the ratio of the remaining capacity to the fully charged one. The change in the state of charge in a given time interval dt, together with the discharge and charging current i can be expressed by the following equation:

$$d\left(SoC\right)=\frac{idt}{Q\left(i\right)} \tag{1}$$

where Q (i) is the battery capacity at a given current i. In this case, the battery status can be expressed by:

$$SoC=SoC_0-\int\frac{idt}{Q\left(i\right)} \tag{2}$$

Where the SoC_0 is the initial value of the SoC.

II. MODELLING OF SUPERCAPACITOR

The modeling of supercapacitors makes it possible to predict their behavior in different applications, while basing these models on a representation of the main physical phenomena appearing within the component.

For the electrician, the supercapacitor is one component among others that are part of an energy system that should be identified:

- for this, it is a priority to have a good energy representation of this component since its main function is storage.

- secondly, it is also important to know its temporal behavior

in order to assess the constraints it places on the rest of the circuit.

Figure 1. shows a basic diagram representing the energetic behavior of supercapacitors through the two main phenomena appearing in storage systems:

- the injection or extraction of charges over generally relatively short durations is quantified through parameters of type (R, C).

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- the presence of a permanently stored charge induces phenomena secondary generating pressure drops and often represented by a resistance leak.

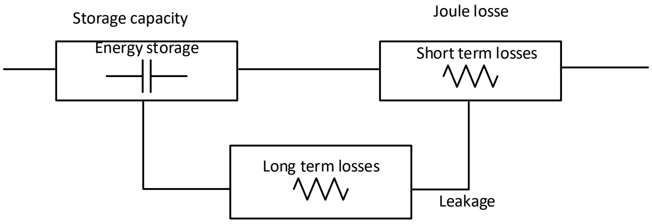

Fig. 1. Basic scheme of behavior of the supercapacitor

Different types of models can be used:

- the models of electrochemists, models that can be qualified as "Microscopic", capable of representing very precisely the phenomena internal.

- “macroscopic” circuit-type models, less close to physical reality but easier to handle.

This synthesis of models can thus be made according to the type of use desired and may favor certain aspects over others:

- model focused on a good temporal response

- model focused on good energy precision

- model intended to represent phenomena on a large time scale (ex: study of the voltage imbalance that may appear during serial use)

- model adapted to a particular use (generally at a defined bandwidth and related to the length of the cycle of use).

In order to model supercapacitors, manufacturers use the similarity between the behavior of the latter and that of electrolytic capacitors. For this a supercapacitor can be characterized by a series resistance (Rc) and a capacitance of storage (CC). With a simple constant current discharge test, it is possible to calculate these two parameters. The difference in voltage level between the end of the discharge phase and five seconds after this discharge phase (Vr) gives the image of the series resistance. The image of the element's storage capacity is given by the voltage drop between the state initial (rest state before discharge) and final state (five seconds after discharge). The figure 2. shows the test used by the manufacturer MAXWELL [C2-8, C2-9] to perform the characterization of a supercapacitor element.

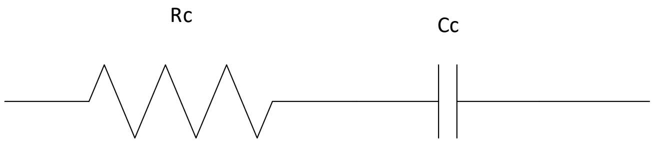

Fig. 3. Model of the supercapacitor

The use of the temporal response of the supercapacitor (Figure 2), Allows calculate the two parameters of the model:

$$C_c = \frac{I_d \cdot t_d}{V_d} \quad (3)$$

$$R_c = \frac{V_r}{I_d} \quad (4)$$

III. MODELLING OF DC-DC CONVERTER

The voltage of supercapacitors are highly variable, the converter must be bidirectional buck/boost. In addition, given the "voltage" nature of supercapacitors, it was chosen at the level of the conversion structure to strengthen their nature by adding capacitors at the input and output of the converter. It was thus necessary to insert a inductance between two reversible current choppers to ensure alternation of sources. Therefore, the input and output filters associated with supercapacitors have low losses (capacitors). Indeed, the dual structure would have required the presence of two inductors and created significant losses in view of the low voltage and high current electrical constraints of supercapacitors.

In Figure 1 a block scheme of the system is proposed including a supplying element, a bidirectional DC-DC converter and energy storage device (supercapacitor).

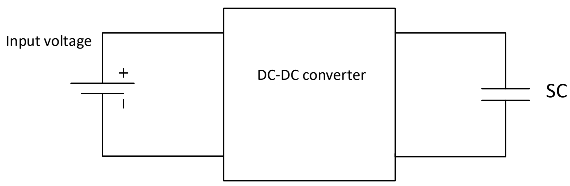

Fig. 4. Block scheme of the studyied system

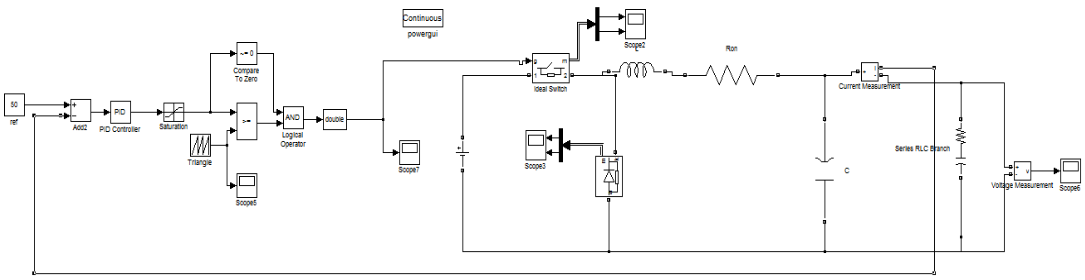

Fig. 2. Buck converter in MATLAB/Simulink

$$L\frac{di_L}{dt}=U_d$$
$$C_{UC}\frac{dU_{UC}}{dt}=i_L \tag{5}$$

$$L\frac{di_L}{dt}+U_{SC}=0$$
$$C_{UC}\frac{dU_{UC}}{dt}=i_L \tag{6}$$

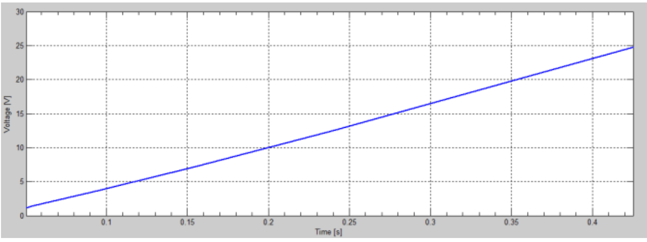

Fig. 5. Voltage of the supercapacitor

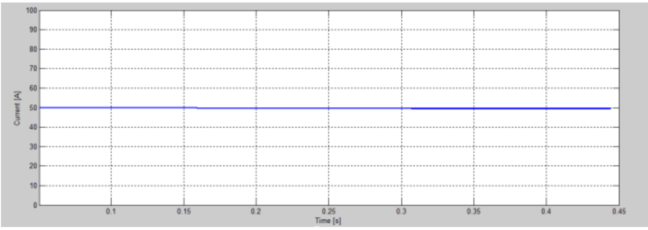

Fig. 6. Current through the supercapacitor

IV. CONCLUSION

Nowadays, supercapacitors arouse a certain interest in the field the design of electrical systems. They are a real challenge in terms of innovation and they go hand in hand with the evolution of current technologies. In the space of a few years, they have become an industrial reality. The companies working in this field are more and more numerous and the volume production of this type of component is very real. Due to targeted applications are already possible. The potential market for supercapacitor is indeed huge: modules of a hundred Farad can replace accumulators in medium power applications such as portable tools, electric toys, electric razors. As well as in electric traction applications (urban transport, electric vehicle and energy renewable).

This component has many advantages which lie in the absence of maintenance compared to solutions consisting of batteries or accumulator, in the lifespan which can exceed 10 years or 1 million cycles. Its performance lie between those of accumulators and those of conventional capacitors. It is both a defect because it is unable to compete with the accumulators if one considers its energy performance. This is also his main asset because he has virtually no competitor in this area. This is what makes him perfectly suited to hybrid systems. Indeed, it allows on the one hand to limit the power sizing of the main source and its infrastructure, and on the other hand, it allows electric braking for electromechanical applications which should induce in the long term an energy saving and therefore financial.

Despite all this interest, the behavior of this component remains poorly understood by users of energy storage systems. Its use in the "strong current" applications require the serialization of a large number of elements. This will necessarily have consequences on the aging of the storage device.

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