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Low cost set-up for supercapacitors parameters evaluation

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Abstract. Supercapacitors are capable to store relatively high amount of energy comparing to its mass. Growing number of these devices applications requires development of new testing methods. Standard methods of evaluation of supercapacitor parameters, as cycling voltammetry, CV, galvanostatic cycling with potential limitation, GCPL, impedance measurements, require equipment of high cost as potentiostat/galvanostat with high current efficiency. We propose a use of a power amplifier in the circuit of voltage to current converter (current driver) for supercapacitor charging/discharging in controlled conditions. The current driver is controlled by DAC output of DAQ board and voltage of DUT is measured and a control loop is realized by software. In the circuit the DC current method of evaluation of capacitance and equivalent series resistance is used. The DUT is charged and discharged with constant current and capacitance C and equivalent serial resistance ESR are calculated from voltage curves. For test purpose commercially available supercapacitors were measured with different current values. The designed test circuit is a low-cost alternative for professional and semi-professional systems. It gives several advantages as easy control of charging current and possibility of applying various current patterns.

1. Introduction

Supercapacitors are devices that are capable to store relatively high amount of energy in comparison with its mass. On a Ragoon plot, where the power density versus energy density of devices is presented, supercapacitors are placed between standard capacitors and batteries [1].

Supercapacitor shows higher value of electric capacitance than a standard capacitor and could be charged/discharged with high current, even of hundreds Amps. Single supercapacitor cell rated voltage is usually 1.5 V for water based and 2.3 V to 2.7 V for organic electrolyte devices. For commercial devices the capacitance starts from about 0.1 F up to thousands of Farads. The rated voltage and capacitance could be extended by connecting the cells in series or in parallel.

Increasing market of supercapacitors and growing number of applications requires control of its electrical parameters. Supercapacitor's quality is usually derived from its capacitance C, equivalent series resistance ESR, equivalent distributed resistance EDR, and impedance.

Commonly used methods for supercapacitors testing are: galvanostatic cycling with potential limitations (GCPL), cycling voltammetry (CV), impedance spectroscopy, and accelerated aging [2-6]. All those methods are based on observation of current and voltage during forced charging/discharging of the supercapacitor at selected bias conditions and requires measurement set-up that allow to control those conditions for wide range of charging-discharging currents and voltages.

Measurement set-up for supercapacitor parameters estimation should be capable to measure a wide range of devices. It should be able to charge supercapacitor in a reasonable time which implies high current values for high capacitance devices. Professional systems for laboratory or production use are usually expensive and its purchase for non-commercial use is not economically justified. Taking into account growing number of semi-professional applications of supercapacitors there is a need for a low-cost set-up for supercapacitors' parameters measurements.

2. Supercapacitor parameters evaluation

The commonly used method of measuring supercapacitor's capacitance and equivalent series resistance is based on observation of voltage while the tested device is charged and discharged with constant current. The voltage curves during measurements are shown in figure 1.

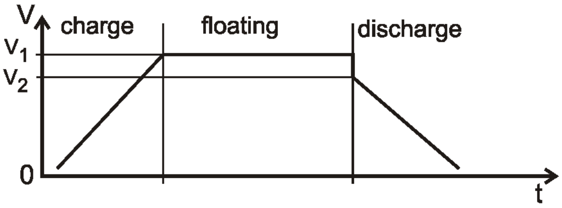

Figure 1. Charging and discharging voltage curve used for capacitance and ESR evaluation.

The capacitance of supercapacitor is calculated using equation (1), while the EST is calculated using equation (2):

$$C = Q / \Delta V, \tag{1}$$

$$ESR = (V_1 - V_2) / \Delta I, \tag{2}$$

where Q is a charge delivered to the supercapacitor by charging with a current I during time t, $Q = I \cdot t$, ΔV is a voltage increase during charging, ΔI is a difference between current at the end of floating and at the beginning of discharging. This measurement requires the current source having efficiency high enough to charge and discharge supercapacitors of the given capacitance in reasonable time. For example, a supercapacitor of 10 F with 2.5 V of rated voltage, according to equations (1) and (2), will be charged during 12.5 seconds with the current of 2 A or during 2.5 seconds with the current of 10 A.

3. Measurement set-up

As a source of charging/discharging current we propose to use a voltage controlled current driver circuit shown in figure 2. In the circuit, shown in figure 2, the output current I_{out} is proportional to the input voltage V_{in} as in equation (3)

$$I_{out} = (\mathrm{R2}\ V_{in})/(\mathrm{R1\ R6}),\ \mathrm{R5} = \mathrm{R4}. \tag{3}$$

In the test circuit, values of R1, R2 and R3 were selected to get $I_{out} = 0.1\ V_{in}$. This simplify the calculation of V_{in} value required for the desired I_{out} value.

In the test system the LM12 amplifier was used. This integrated circuit is capable to deliver 10 A output current and operate with supply voltage up to ±30 V. The amplifier could be replaced by any high power amplifier capable for DC operation. The amplifier circuit was supplied by two 12 V acid-lead batteries.

The supercapacitor under test is connected to the measurement set-up through the test circuit that comprises of two electromagnetic relays and two resistors: one for current measurement, one for discharging supercapacitor if required. The test circuit is shown in figure 3.

The R1 resistor in the test circuit is used to monitor current and its value is low (about dozens of mΩ). Charging current is calculated as $I_{charge} = (V1 - V2)/\mathrm{R1}$. The supercapacitor voltage is directly measured as $V1$. Resistor R2 is used for discharging device with a constant resistance (e.g. during noise measurements [7]). Resistor R2 could be replaced by another type of the equipment if needed (e.g. active load, power source of different type). Electromagnetic relays S1 and S2 are used for connecting and disconnecting the supercapacitor to the current source and load resistor respectively.

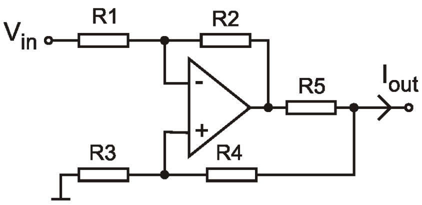

Figure 2. Current driver circuit.

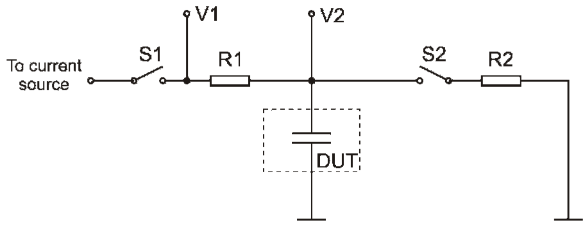

Figure 3. Test circuit; DUT is a supercapacitor device under test.

The measurement set-up is controlled through data acquisition board with analog-to-digital converter (ADC), digital-to-analog converter (DAC), and digital lines. DAC is used for current control by applying voltage to the input of current driver. ADC is used for voltages measurement and digital lines control relays state. In the developed circuit we used National Instrument USB 6009 universal data acquisition board.

4. Measurement results and discussion

Measurement set-up was tested with commercially available supercapacitors Nesscap ESHSR-0010C0-002R7, 10 F, 2.7 V. Devices were charged and discharged with current having various values. Exemplary voltage dependences for two current values 2 A and 8 A are shown in figure 4. Device was charged, left open circuit for 1000 s and discharged. Before each experiment device was discharged by short-circuiting for at least 24 hours.

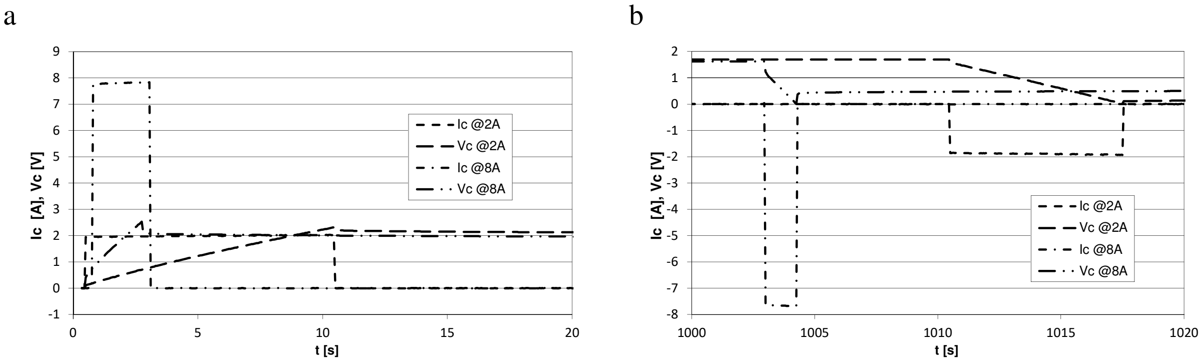

Figure 4. Voltage and current for charging (a) and discharging (b) supercapacitor with 2 A and 8 A.

From charging and discharging curves capacitance C and resistance ESR were calculated according to equations (1) and (2). The results for different current are stored in table 1.

Table 1. Capacitance C and resistance ESR calculated for different values of charging and discharging currents.

	2 A	4 A	8 A	10 A
C (charge/discharge) [F]	8.60/7.91	7.96/7.38	7.09/6.13	6.69/5.47
ESR [Ω]	0.054	0.053	0.053	0.053

The differences in the measurement results for different current values are explained by commonly used electrical equivalent model of supercapacitor shown in figure 5 [8,9]. The model comprises of two branches. The first branch with ESR and the capacitance C_H representing Helmholtz layer capacitance, which is available for fast charging-discharging, as value of ESR is relatively low. The second branch with the capacitance C_D represents capacitance of diffusion layer. The resistor R_D determines how fast diffusion occurs [10]. The second branch represents slow states, that are available for charging for longer times.

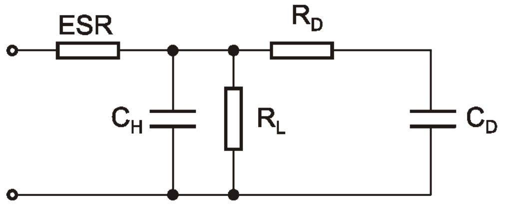

Figure 5. Electrical equivalent model of supercapacitor.

While discharging supercapacitor using high current the capacitance C_H is discharged much faster than C_D. The near-zero potential between the supercapacitor's terminals is reached even when C_D is not fully discharged. The capacitance is estimated by equation (1) and corresponds more to C_H value than to total capacitance of the specimen.

5. Conclusions

We propose a low cost measurement set-up based on current driver for charging/discharging supercapacitors. Measurement set-up is interfaced by standard low-cost data acquisition board with the converters ADC, DAC and digital lines, and is controlled by software application. Similar solutions were applied for noise measurements set-up with a necessary bias conditions as in the presented case [11]. The proposed architecture is flexible: the data acquisition board could be replaced by a popular microcontroller platform, as Arduino. Applied current driver could be used also for testing supercapacitor with different patterns of current. The proposed test circuit additionally expands functionality of the set-up. It allows for charging/discharging the tested devices in different ways: with constant current, constant resistance and with use of external active load.

Acknowledgments

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