Stand for Automatic Measurement of Time Variation of EDLC Specific Electrical Parameters

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Topic: 2

Presentation: P

Summary: **Batteries that store electric energy in industrial applications or in automotive have some disadvantages as: limited number of charge-discharge cycles (lead-acid batteries), high price (NiMH and Li-ion) or their slow (minimum) charging time. Today a good alternative to the classical accumulator is the Electrochemical Double Layer Capacitor (EDLC) or Supercapacitor. This paper presents an automatic system for the study of supercapacitors. The most important advantage of the EDLC component is its capability to withstand 300,000 charge-discharge cycles. For optimal use of EDLC is necessary to know the temporal dependence with temperature of electrical signals (discharge current, load current, voltage at capacitor terminals). A test platform was developed, based on a computer-controlled measurement system (MS) and a climatic chamber. The MS is the central part of automatic measurement of the time behavior of EDLC electrical signals. The climatic chamber has programmable environment temperature.**

Keywords: storage, system, energy, EDLC

I. THE MAIN PARAMETERS OF EDLC

The main parameters of EDLC that should be taken into account in the development of applications are the following:

- *Rated voltage* – usually has low values (2.5V…2.7V). An EDLC should be used within the limit of the rated voltage value. If the EDLC experiences a voltage that exceeds this value, permanent damage and eventually the destruction of the capacitor can occur;
- *Equivalent Series Resistance* ESR – influences the behavior of EDLC in applications because as its value increases so does the value of the leakage current. In practice we want supercapacitors with low equivalent series resistance.
- *The leakage current* – varies in time and depends strongly on the ambient temperature, the maximum charging current, the charging voltage and the time which is kept under voltage after EDLC is loaded and falls below a certain limit.

II. CLASSIC STAND FOR SELF-DISCHARGING MEASUREMENT

This stand (see Fig. 1) is composed of more set of devices (a programmable power supply, voltage and current meter), one set for each EDLC under measurement. The biggest disadvantage of this stand is that it requires permanent human supervision and for a period of time a large number of professional equipment is unavailable for other activities. With such stand 6 capacitors of 1200F /2.5V were measured.

Fig. 1 The classic measurement stand in operation

III. AUTOMATED MEASUREMENT STAND OF TIME VARIATION OF EDLC SPECIFIC PARAMETERS

The block diagram of the automated measurement system is presented in fig. 2 and an overview of the real implementation with physical equipment can be seen in Fig. 3. The system includes measurement equipment such as: programmable power supply (current/voltage), digital multimeter, data logger, scanner and PC interface (USB/GPIB). All devices are controlled by specialized instrumentation software.

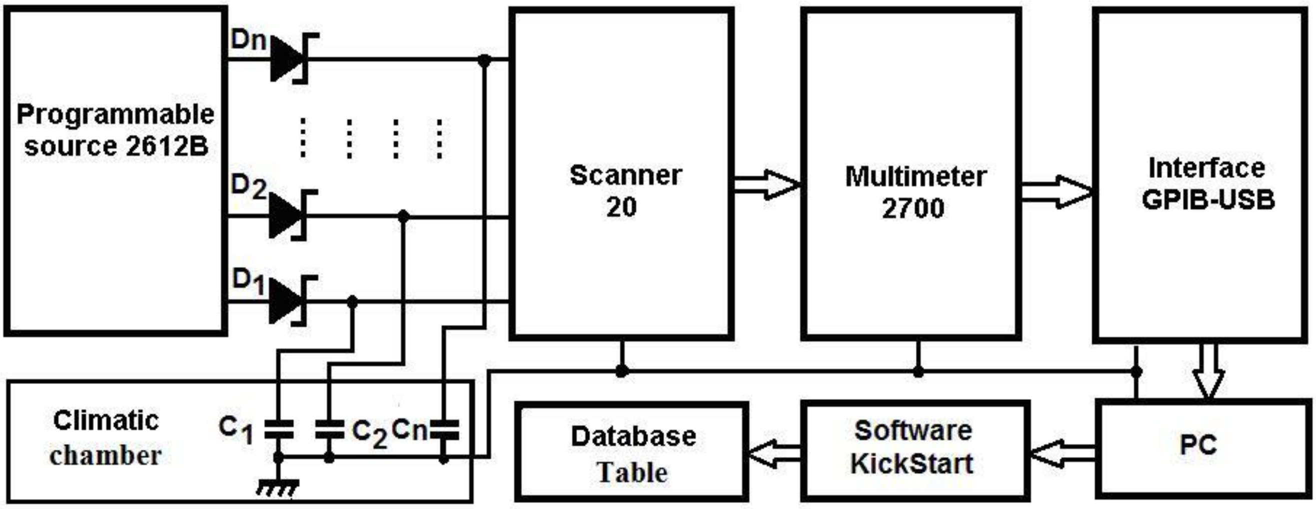

Fig.2 Automated measurement system for time dependent parameters of EDLC

The system contains a Keithley 2612B programmable power supply which can control the charging current, the maximum charging voltage, as well as, in certain situations, the discharge current. In our case, because we have only one power supply, for the study of leakage current, the separation of the capacitors is done by means of diodes D1 ... Dn that prevent loading of a capacitor by the others. The Keithley 2700 multimeter supervises the scanner, actually a multiplexer with a total of 22 channels. The scanner consists of 20 channels for measurement of voltages, resistances, thermistors and thermocouples and 2 channels for current measurement. The multimeter, through a GPIB-USB adapter, does the cyclic measurements and sends them to a PC. Data is processed and tabulated using the KickStart software and it is possible to monitor and analyze the main parameters of EDLC. In addition, the multimeter has the capability of storing data (in Excel format) through the data logger that can be used through a command by the PC.

Fig. 3 Overview of the automated measurement system

KickStart is a specialized instrumentation software that controls the whole system; it can present graphs and diagrams in different formats. Because the measurements take very long times (weeks), only few experiments have been completed so far.

IV. RESULTS

1. The loading of EDLC using the stand with automated control

A first test was pulse loading of 3 EDLCs with 400F capacity.

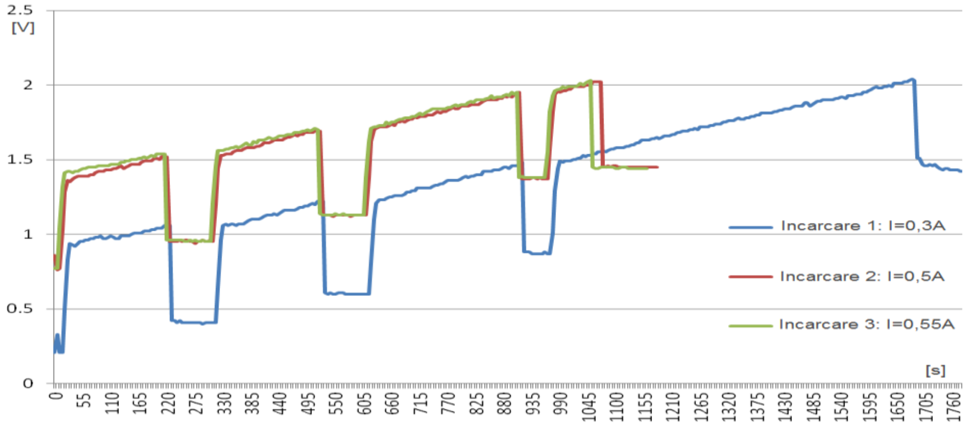

Fig. 4 The loading of 400F EDLC with 0.3A ... 0.55A current

As long as current flows through the capacitor, the voltage across its terminals will increase. When the load current is switched off, capacitor voltage decreases with approx. 0.6V. Because the increase is in pulses, in the moment when current is applied again, the voltage has a lower value than the voltage when the current was switched off. This effect is caused by the considerable self-discharge of EDLC in the first seconds after the charging pulse ends. When the voltage has reached the maximum value of 2V, the diodes are no longer open and the power supply connection is blocked (switch in the off state). In this moment, the charging current is switched off and the self-discharge of the supercapacitor is the only phenomenon that occurs, a process that lasts a very long time.

2. *Self-discharge of EDLC*

a. Self-discharge of voltage

The self-discharge was monitored for one of the 3 EDLC which was charged in 0.5A current pulses up to the maximum 2V voltage. The results are presented in Fig. 5.

A faster discharging in the first part (the first day) and then slower discharging can be observed. After 50 days a 0.5V voltage decrease occurs.

b. Leakage current of EDLC

The leakage current is a very important parameter of EDLC. It must be taken into consideration in the development of applications because a high leakage current can discharge fast the EDLCs.

In table 1 the values of leakage current for 6 different 1200F supercapacitors are presented. Data is measured after their maximum voltage of 2.5V was reached and then kept at this value for 2 or 4 hours. A decrease in leakage currents that depends of load voltage can be observed.

To check the time behavior of leakage current the 400F EDLC was placed in a standard climatic chamber and temperature was varied.

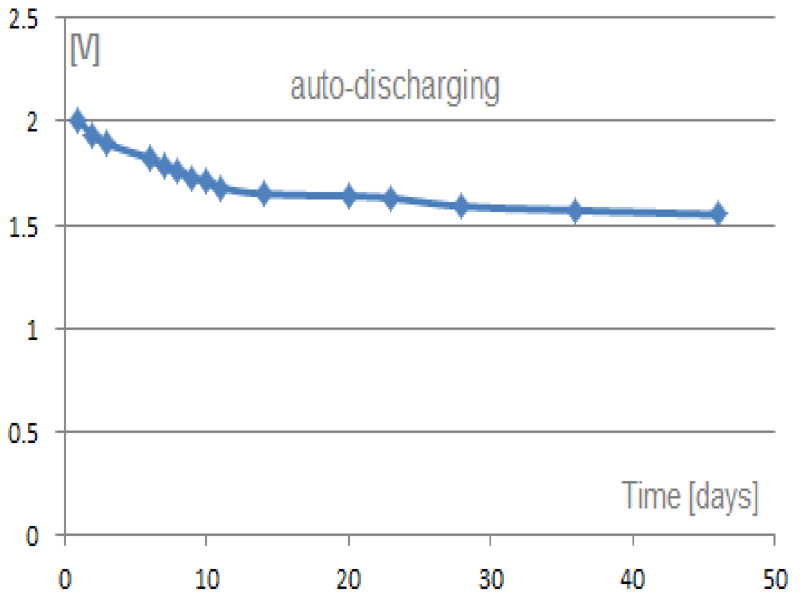

Fig. 5 The self-discharge of 400F supercapacitors

TABLE I

THE LEAKAGE CURRENT AT 20°C FOR 6 SUPERCAPACITORS KEPT AT 2.5V FOR 2/4HOURS

No.	**Load voltage [V] Time 2 hours**	**Leakage current [mA] After 2 hours**	**Load voltage [V] Time 4 hours**	**Leakage current [mA] After 4 hours**
1.	2,47	0,38	2,46	0,27
2.	2,62	0,20	2,61	0,15
3.	2,12	2,08	2,12	1,48
4.	2,48	1,04	2,49	0,98
5.	2,59	0,24	2,58	0,20
6.	1,96	2,09	1,98	1,52

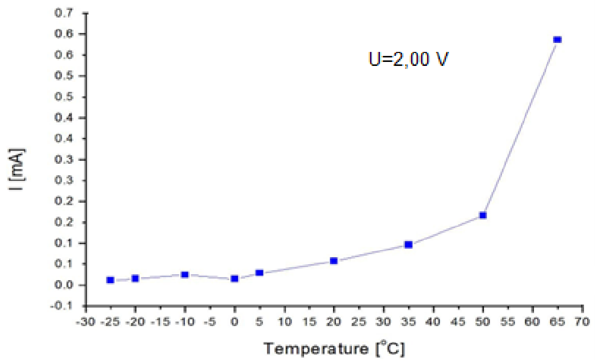

Fig. 6 The variation of leakage current of one EDLC of 400 F at various temperatures

Fig. 6 presents the leakage current of the supercapacitor depending on ambient temperature; for negative temperatures we have a very low leakage current, favorable situation in applications, but, as the temperature rises, a considerable increase of the leakage current can be observed, especially at temperatures over 40 degrees Celsius. Thus at 65 degrees Celsius we'll have a value of the leakage current of 0.6 mA, unfavorable situation in some applications of energy storage for large periods.

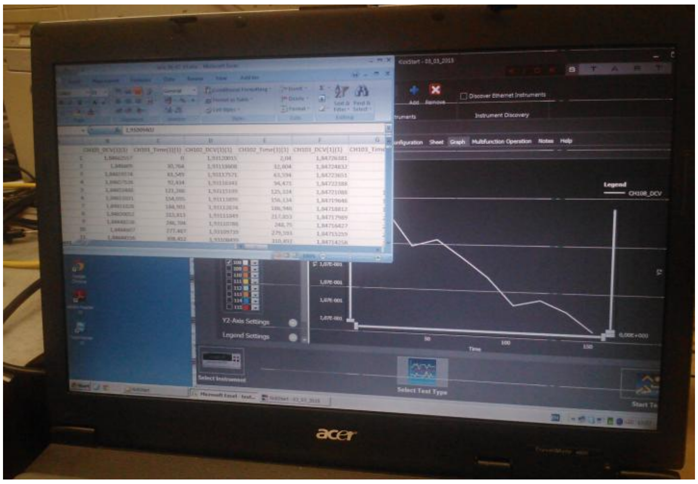

Fig. 7 The discharging of supercapacitor of 400F in pulses

Fig. 8 The supercapacitor battery consisting of 6 devices with 600F capacity coupled in series with a total rated voltage of 12 V

Figure 7 shows the diagram of 400F supercapacitor discharge at 2A current pulses. Through a simple modification of the KickStart software of the automatic system the supecapacitor can be charged with 1A current pulses.

3. Future developments

With a battery pack of EDLCs with 12 V rated voltage (see Fig. 8) future experiments for the automotive industry can be performed. The EDLCs are about to become a good alternative compared with lead-acid batteries, considering their advantages, especially their ability to work at negative temperatures and their large current capability.

V. CONCLUSIONS

The supercapacitors have advantages and disadvantages compared to batteries in energy storage applications. Therefore, in some applications it is preferred to use hybrid systems based on batteries and supercapacitors.

The supercapacitor is a viable solution for use in a hybrid electric system. Its advantage is the higher number of charge/discharge cycles, their use being beneficial as well for the peaks of power they can supply.

The supercapacitor has the capacity to store the short-term deceleration energy in a car, and to later transfer the recovered energy to the motor. The advantages are reducing battery wear (increasing life-time / cycle for application) and full recovery of the generated energy during braking by electric motor.

One application of these batteries may be in the automotive field, where it is necessary to store more energy and where, due to the toxic hazard of the large lead-acid accumulators, it is recommended to replace them with a clean system.

Other applications in the automotive field are improvement of the internal combustion engine, ensuring its ignition at low temperatures, as well as at hybrid electric vehicles, where the efficiency grows by using EDLC for breaking energy recovery).

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