Experimental Verification of Internal Resistance and Capacitance of CPQ2300S Li-Ion Ultracapacitors (JSR Co.)

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***Abstract*— Electrical storage facilities are becoming an inherent element of the present and future renewable power plants. Among different storage technologies stand out double-layer ultracapacitors (UC) with high power density during charge/discharge processes and extremely prolonged service life.**

Between these appliances Li-ion hybrid UCs could be noted as having twofold higher energy density and service life compared to that of conventional double-layer devices. Internal resistance and capacitance of these devices aren't yet quite examined in the wide range of parameters: voltage, current and temperature since it is relatively new technology (5-6 years from the first manufacturing only).

Given article represents investigation of the internal resistance and capacitance of CPQ2300S ultracapacitors (2300F, 2.2-3.8V, manufacturer JSR Co.) in wide range of their currents and voltages in temperature limits from -40°C to +30°C. Results of this work could be important and useful for the storage facilities development based on the ultracapacitors application.

Keywords—Li-ion ultracapacitors; internal resistance; temperature dependence

I. Introduction

Further increase of renewable energies introduction to the present power grids as well as improvement of quality, sustainability and cost effectivity of electrical systems couldn't be done without electrical storage facilities. That is why multiple efforts continue to be carried out to enhance design and development of existing and new electrical storage appliances.

Among new promising technologies of electricity accumulation are Li-ion hybrid ultracapacitors having twofold higher energy density and service life compared to that of conventional double-layer ultracapacitors [1, 2]. In spite of being relatively voluminous and bulky relative to electrochemical storage batteries (such as Li-ion or Lead-Acid) they are three orders in magnitude better in terms of service duration.

These devices were put into practice only 5-6 years ago. This circumstance explains a lack of careful information regarding their functionality and parameters describing equivalent circuit's data. Internal resistance and capacitance trends especially during temperature decrease are among the most important parameters that attract attention during new facilities design [3, 4, and 5]. Experimental investigation of these parameters is the major subject of the presented article.

II. Methodology of Experimental Research

Experimental research of internal resistance and capacitance was carried out on the special equipment (Fig.1) including UC CPQ2300S (2300F, 2.2-3.8V**),** electronic load (EL) (PLZ1004W, KIKUSUI), data acquisition module (DAQ) ADLINK (2 MS/sec, 16 bit) and laptop PC for recording measurement data. Principle electrical circuitry is drawn in Fig.2.

Fig.1. Experimental setup

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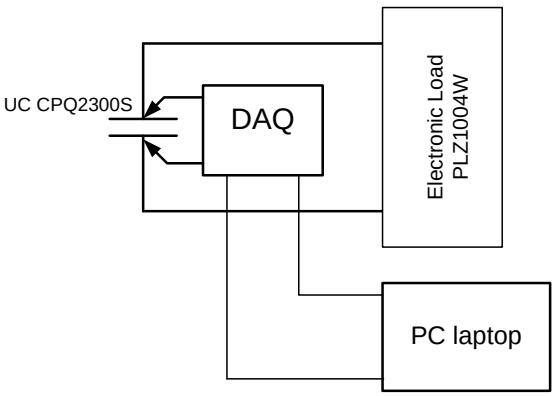

Fig.2. Electric circuit of measurements

Test procedure was carried out as follows. On the first stage UC was being charged to a voltage which is a little bit less than its maximum permissible value (3.70-3.75V). After this UC was connected to EL and discharged with pulsed however constant current (2 sec pulse and 5 sec rest period) which value for a single test was chosen between 10-100A. Special freezing chamber was used for temperature tests.

Discharge process was escorted by diminished voltage. Therefore it was automatically finished by EL once voltage had being achieved minimum permissible level of 2.2-2.3V.

UC voltage was measured by DAQ with time resolution of 10 ms and recorded in PC. Typical voltage curve is shown in Fig.3.

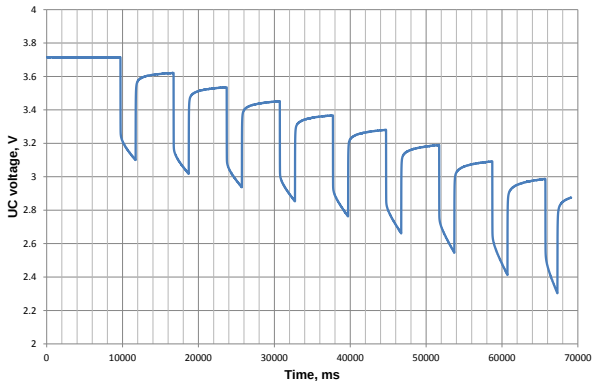

Fig.3. Typical voltage curve during UC discharge

Parameters of internal resistance and capacitance were estimated by the following procedure which graphical explanation is represented in Fig.4.

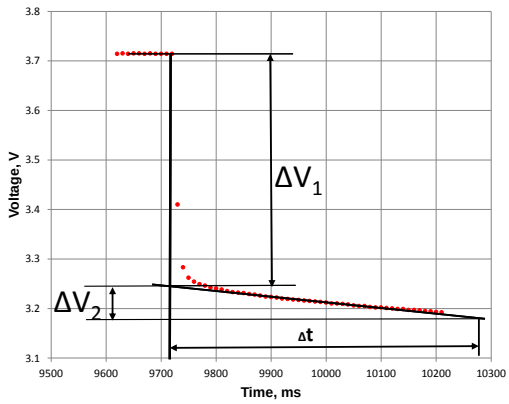

Fig.4. Graphical explanation of parameters estimation

Firstly trend line over points of steady voltage decrease has to be drawn. Trend line allows estimating ΔV_1 which describes initial UC voltage drop immediately after applying discharge current. Therefore, internal resistance could be assessed by following expression:

$$R_{\text{int}} = \frac{\Delta V_1}{I_{disch}}$$

Secondary, trend line lets calculation of voltage derivative versus time that is equal to:

$$\frac{dV}{dt} \approx \frac{\Delta V}{\Delta t} = \frac{C}{I_{disch}}$$

As a result, capacitance can be estimated as:

$$C = \frac{I_{disch}}{\left(\frac{\Delta V_2}{\Delta t}\right)}$$

Where I_{disch} is the current that EL was applied on UC, C - capacitance.

III. Experimental Results

Results of UC CPQ2300S resistances and capacitances experimental verification for 20A and 100A are represented in graphs Fig.5 (a, b) for the temperature +25°C.

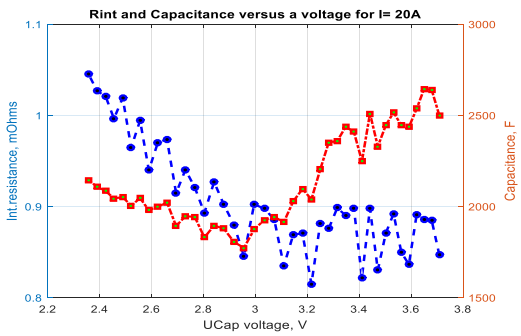

Fig.5a. Internal resistance and capacitance versus UC voltage for discharge current 20A for +25°C.

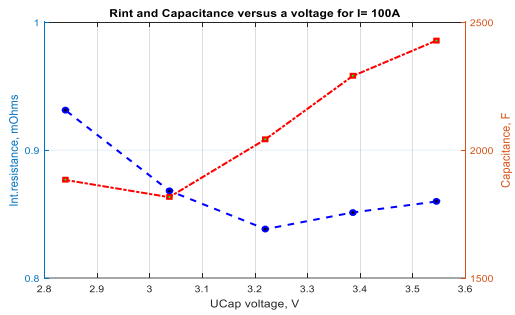

Fig.5b. Internal resistance and capacitance versus UC voltage for discharge current 100A for +25°C

Dependences of the same parameters for -20°C are shown in graphs Fig. 6(a, b).

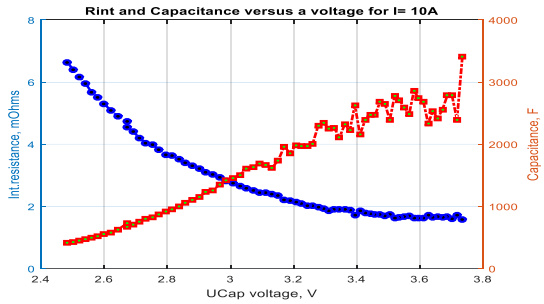

Fig.6a. Internal resistance and capacitance versus UC voltage for discharge current 10A for -20°C.

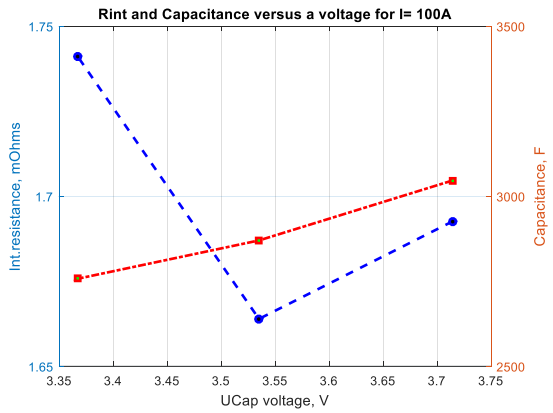

Fig.6b. Internal resistance and capacitance versus UC voltage for discharge current 100A for -20°C.

Brief analysis shows that internal resistance grows significantly during UC discharge and for negative temperatures. Thus, resistance increases 60-70% over nominal value when voltage decreasing from maximum to minimum permissible level for relatively small currents and positive temperature +25°C. This increase becomes much lower (17-18%) for higher current (100A) at the same temperature. However the final voltage when EL has to end discharge process turns out to be more significant since for the same current voltage drop is higher and UC terminal voltage is smaller. Therefore for bigger discharge currents and high resistances the usage of entire UC stored energy becomes impossible.

UC capacitance has the similar tendency during discharge process as a resistance. Capacitance reduction approximately is equal to 13-14% and 29-30% for 20A and 100A respectively in room temperatures during UC discharge from being full to empty level. Capacitance is decreasing much more significant for negative temperatures especially for small current (10A) and its initial value 4.2-4.4 time more than that of fully discharged UC. In spite of the substantial decrease during discharge initial capacitance in the low temperature is bigger than its nominal value.

Parametrization of UC parameters during discharge implemented in the present article can provide optimal design of the storage facilities working in a wide range of applied currents and environmental conditions.

IV. Results and Conclusions

Preliminary results showed significant dependence of internal resistance and capacitance parameters on the temperature, UC current and UC voltage.

Both internal resistance and capacitance go bad with UC discharge from full to empty state. Internal resistance can increase its value up to 4-5 times in the cold conditions and this circumstance has to be taken into account very seriously in the development storage facilities with Li-ion UC intended to work in the negative temperatures.

Increase of discharge current can improve internal resistance making its value lower. However applying higher current causes diminishing the value of energy stored in UC.

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