A COMBINED METHOD FOR MEASURING SUPER-HIGH CAPACITORS ABSORPTION CHARACTERISTICS.

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Abstract - The paper is devoted to measuring of super-high capacitor energy characteristics with direct current. The authors investigated the mathematical models of super-high capacitors with direct current stable source and proposed new combined method and variation-current method for measuring energy characteristics of super-high capacitors.

Keywords - combined method, variation-current method, super-high capacitor, equivalent circuit, energy characteristics, stable current source.

By analyzing the super-high capacitors equivalent circuit, it is possible to make a conclusion: this circuit consists of the R_AC_A absorption circuits.

Actually, the nature of the real super-high capacitors is much more complicated. The presence of both capacity and losses active resistance are obvious. Besides, they are distributed under the defined law on a length or on a volume of the super-high capacitor constructive space.

Graphically, fragment of the super-high capacitor constructive space can be illustrated by the Nguyen Thien-Chi and J. Vergnolle equivalent circuit, fig.1 [1].

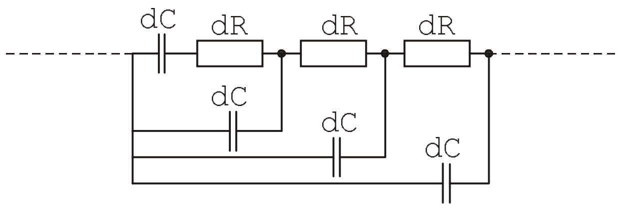

Fig. 1. The Nguyen Thien-Chi and J. Vergnolle equivalent circuit.

The elementary differential capacity dC circuits are charged through the elementary differential resistance dR circuits in this equivalent circuit. Depending on a capacitor construction these dC and dR circuits are allocated either on a length dl or on a volume dof the capacitor constructive space.

Such approach at the mathematical exposition of real super-high capacitors is the most correct, however, is complicated enough. The transition from differential dC and dR elementary circuit to the absorption capacitance C_A and resistance R_A equivalent circuits allows experimentally to confirm the considered mathematical capacitor model with a defined accuracy.

The super-high capacitor mathematical model equivalent circuit is shown in fig.2.

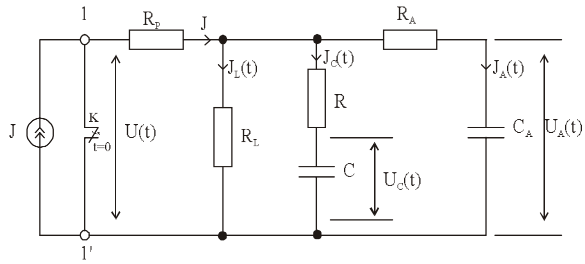

Fig. 2. The super-high capacitor mathematical model equivalent circuit.

In this equivalent circuit: Rp is the pin resistance; R_L is the leakage resistance; R is the active serial resistance; C is the main capacitance; R_A is the absorption resistance; C_A is the absorption capacitance; J is the stable current course (J=const).

According to this equivalent circuit the authors propose new combined method for measuring of the C_A and R_A absorption characteristics. This method is explained by the timing diagram in fig.3.

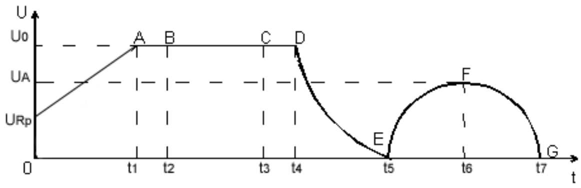

Fig.3. The combined method timing diagram.

The essence of combined method consists of four stages.

1) At first the super-high capacitor is charged from stable current source (J=const) to the defined voltage U_0. By measuring the voltage U_{Rp} and time t_1 we can define the main resistance C, the resistance R_P and R.
2) At the second stage, it is necessary to switch the super-high capacitor to the stable voltage source ($E=U_0$=const) and to charge the main capacitance C and absorption C_A completely.
3) At the third stage we discharge the main capacitance C quickly so that we don't discharged the absorption C_A.
4) After that we have to disconnect the super-high capacitor from source and to wait when the voltage will be equal to maximum value U_A.

In this case the charge passed from capacitance C_A to capacitance C. This process is shown in fig.4.

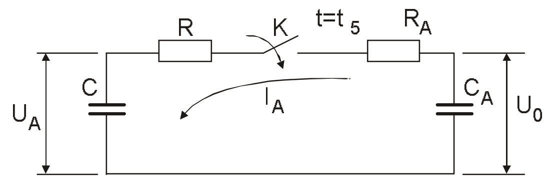

Fig.4. Recharging the capacitance C from capacitance C_A.

The absorption capacitance C_A and rasistance R_A can be found out by the expressions:

$$C_A = C\frac{U_A}{U_o - U_A} \tag{1}$$

$$R_A = \frac{t_6}{C\,\ln\left(\frac{U_A}{U_o}\right)} - R \tag{2}$$

The proposed method allows to define the electrical parameters of super-high capacitor equivalent circuit fig.2. To measure this parameters authors propose the super-high capacitor analyzer block diagram fig.5.

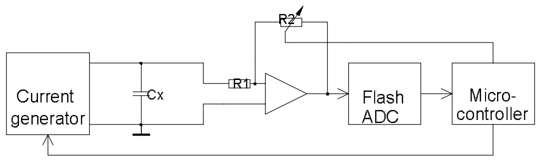

Fig.5. The super-high capacitor analyzer block diagram

During design, manufacture and maintenance of super-high capacitors, there is a problem for monitoring of their energy characteristics. It is important to know not only maximum electrical energy, which can be accumulated by the super-high capacitor, but also its ability to return this energy at different values of load impedance [2].

The knowledge of such performances allows forecasting the ability to support a voltage rating of the super-high capacitor on a load in a given limitation during a particular time interval at different loads. Besides, the determination of a discharge current maximum value of the super-high capacitor and maximum time interval, during which the load voltage will be in necessary voltage range, is important too.

Monitoring of these super-high capacitor energy characteristics gives the answer to a problem, by what maximum enabled current is possible to charge the super-high capacitor and how long it takes.

Also, the self-discharge parameters of such capacitors are important for user application of super-high capacitors.

According to circuit theory, the equivalent circuit for charging super-high capacitor looks like fig.6.

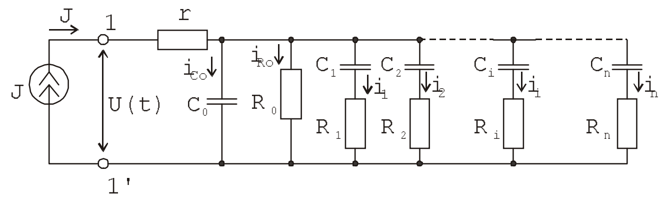

Fig.6. The equivalent circuit for charging of the super-high capacitor by a stable current source J=const.

In this equivalent circuit: r is an equivalent active resistance of losses; C_0 is a geometrical (non-inert) capacity; R_0 is an active leakage resistance; R_iC_i are n - relaxation circuits.

The source current J will be distributed on the currents of the relevant sections of the super-high capacitor equivalent circuit:

i_{R_0} is a current that goes through the resistance R_0;

$i_{C_0} = C_0\frac{\partial U_0}{\partial t}$ is a charge current of the capacity C_0;

$i_i = C_i\frac{\partial U_i}{\partial t}$ is relevant current of an i- section.

Therefore,

$$J = i_{R_0} + i_{C_0} + \sum_{i=1}^{n} i_i \tag{3}$$

The voltage U(t) that occurs on pins 1-1' of the super-high capacitor in a time of a charge by the stable current source J, is determined by expression:

$$U(t) = Jr + R_0 i_{R_0} \tag{4}$$

In this expression the second item is a voltage drop U_0 on a parallel-connected circuits of an equivalent circuit:

$$U_0 = R_0 i_{R_0} \tag{5}$$

Let's differentiate this expression (5), taking into account, that $\frac{dU_0}{dt} = \frac{i_{C_0}}{C_0}$:

$$\frac{dU_0}{dt} = R_0\frac{di_{R_0}}{dt} = \frac{i_{C_0}}{C_0} \tag{6}$$

On the other hand, the voltage U_0 equals to sum of drop voltages of the capacity C_i and the resistance R_i of the relevant circuit of absorption.

$$U_0 = U_i + R_i i_i \tag{7}$$

Let's differentiate this expression (7) taking into account, that $\frac{dU_i}{dt} = \frac{i_i}{C_i}$:

$$\frac{dU_0}{dt} = \frac{dU_i}{dt} + R_i\frac{di_i}{dt} = R_0\frac{di_{R_0}}{dt} \tag{8}$$

Taking into account expressions (3)...(8) we shall write a system of a differential equations, that describes the process of a charge of the super- high capacitor by a stable current source J for an equivalent circuit of fig.6.

$$\begin{cases} i_{R_0} + i_{C_0} + \sum_{i=1}^{n} i_i = I \\ i_i + R_i C_i \dfrac{di_i}{dt} = R_0 C_i \dfrac{di_{R_0}}{dt} \\ i_{C_0} = R_0 C_0 \dfrac{di_{R_0}}{dt} \end{cases} \tag{9}$$

Taking into account, that $R_0 C_0 = \tau_0$, $R_i C_i = \tau_i$ and $R_0 C_i = \tau_{0i}$, it is possible to express the system (9) as:

$$\begin{cases} i_{R_0} + i_{C_0} + \sum_{i=1}^{n} i_i = \hat{I} \\ i_i + \tau_i \dfrac{di_i}{dt} = \tau_{0i} \dfrac{di_{R_0}}{dt} \\ i_{C_0} = \tau_0 \dfrac{di_{R_0}}{dt} \end{cases} \tag{10}$$

The common decision of an equation system (10) looks like:

$$\begin{cases} i_{R_0} = i_{R_0}^{*} + i_{R_0}^{**} \\ i_{C_0} = i_{C_0}^{*} + i_{C_0}^{**} \\ i_i = i_i^{*} + i_i^{**} \end{cases} , \tag{11}$$

Where $i_{R_0}^{*}$, $i_{C_0}^{*}$ and i_i^{*} are complete solutions of a homogeneous system of equations ("free" current components of circuits);

$i_{R_0}^{**}$, $i_{C_0}^{**}$ and i_i^{**} are partial solutions of an inhomogeneous system of equations ("forced" current components of circuits).

The components $i_{C_0}^{*}$ and i_i^{*} decrease when time increases. Besides, when t→∞ they come to zero. And the component $i_{R_0}^{*}$ increases when time increases. Besides, when t→∞ $i_{R_0}^{*}$ →J.

The components $i_{R_0}^{**}$, $i_{C_0}^{**}$ and i_i^{**} at t→∞ characterize steady currents of sections in an equivalent circuit, fig.6.

Taking into account, that the circuit feeds from a source of a stable current I the steady currents of sections accordingly are equaled:

$$i_{R_0}^{**} = J \text{ , } i_{C_0}^{**} = 0 \text{ and } i_i^{**} = 0 \text{ .}$$

The solutions $i_{R_0}^{*}$, $i_{C_0}^{*}$ and i_i^{*} of a homogeneous system are possible to present as:

$$\begin{cases} i_{R_0} = \sum_l A_{R_{0l}} e^{P_l t} \\ i_{C_0} = \sum_l A_{C_{0l}} e^{P_l t} \\ i_i = \sum_l A_{i_l} e^{P_l t} \end{cases} \tag{12}$$

If to substitute expression (12) in to a system (10) and to balance expressions for identical exponential curves $e^{P_l t}$, we will get a ratio between coefficients $A_{R_{0l}}$, $A_{C_{0l}}$ and A_{i_l}.

$$\begin{cases} A_{C_{0l}} = \tau_0 P_l A_{R_{0l}} \\ A_{i_l} = \dfrac{\tau_{0i}}{1 + \tau_i P_l} A_{R_{0l}} \end{cases} \tag{13}$$

We shall substitute expression (12) and (13) for any l in the first equation (10) and we shall reduce $A_{R_{0l}}$. Then we shall receive a secular equation for calculation all P_l of solutions of an equation.

$$1 + \tau_0 P + \sum_{i=1}^{n} \frac{\tau_{0i}}{1 + \tau_i P} = 0 \tag{14}$$

The index l in the equation (14) is dropped. This equation has l of the radicals and after its solution each of the radicals can assign the index l.

In a general view the expression for the radicals of a secular equation looks like:

$$P = -\sum_{i=1}^{n} \frac{1 + \tau_{0i}}{\tau_0 + \tau_i + \tau_0 \tau_i} \tag{15}$$

Conclusion

By using this mathematical models authors propose the new combined and variation-current methods for measuring the super-high capacitor energy characteristics.

REFERENCES

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[2] F. Grinevich, M. Surdu *Precision variation measuring systems of alternating current*. Kiev, 1989 –192p.