Study on the energy storage of super capacitor

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Abstract

Super-capacitor is now widely used in the field of industry and daily life. With a view to improve the availability factor of Super-Capacitor, we studied the interrelationship among Super-Capacitor energy storage capacity, charging current and leakage current through a large number of experimental data analysis. Based on those experiments we draw the conclusion that super capacitor energy storage capacity tends to be stable after cycle usage; with medium-sized charging current it reaches the maximum storage capacity, while quick charge with high current will reduce its energy storage capacity.

Keyword: energy storage; Super-Capacitor; charging current; leakage current

1 Introduction

Super-Capacitor is a kind of electrochemical element whose process of energy storage is reversible. There is no chemical reaction and environmental pollution during the working time[1].The Super-Capacitor can be safely charging with large current in short time[2].

Super-Capacitor is used widely because of its many advantages. Such as it has high energy density and high power density, it is durable and longevous, it has wide working temperature even can work at –40℃～+70℃, it can fully charged in seconds and has high reliability even charging over time. It has low impedance, millions of cycles and high cycle efficiency(95% or more) ,it is widely used as a standby power supply, solar charger, alarm device, home appliances, camera flash and aircraft, especially it has attracted the widespread attention to the development and applications in the field of electric vehicles[3-6].

The principle of Super-Capacitor energy storage is based on the electrical double layer structure of porous materials-"electrode/solution"[7]. From the analysis of impedance angle, Super-Capacitor can be equivalent for a general RC circuit with reference to S.A.Hashmi's simulation circuit [8-10]. The equivalent model of the Super-Capacitor has been shown in Figure 1.

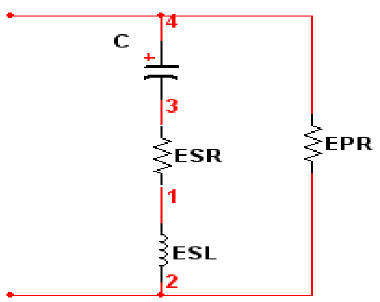

FIGURE 1 Equivalent model of Super-Capacitor

In Figure 1, EPR is the equivalent parallel resistance, ESR is the equivalent series resistance, C is the equivalent capacitance, ESL is the capacitance inductance. EPR is usually very big, it can reach tens of thousands of ohms, and it mainly affects the leakage current of the Super-Capacitor who affects the performance of long term energy storage. ESL is the perceptual components of capacitor, which is related to working frequency.

2 The influence of capacitance characteristics of energy storage

Super-Capacitor stores the energy in form of electric charge. According to the formula: $Q = U \times C$, the amount of charge Q depends on the capacity of the capacitor C and the capacitor voltage U.

The capacitor may be damaged if the voltage U higher than the rated voltage. Study on the capacitive energy storage characteristics, require accurate measurement of capacitance value, it generally uses as constant current discharge method. The test circuit is shown in Figure 2.

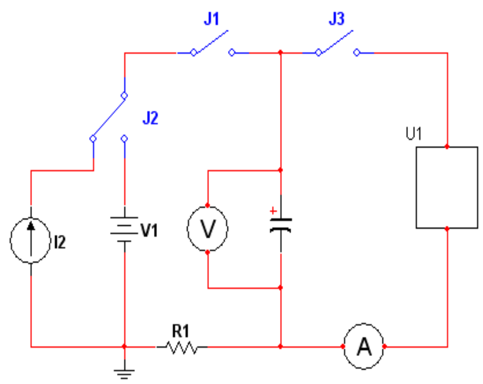

FIGURE 2 The test circuit of capacitance

The specific steps are as follows:

(1) Connect the switch to the constant current source I2, charge the Super-Capacitor with the constant current I.

(2) When the voltage on C1 reached the rated voltage UR,s witched J2 to V1,and charged 30 minutes by the constant voltage.

(3) After 30 minutes' charging, disconnected J1; Measured voltage U1 on the capacitor, then connected J3, record the time t1.The Super-Capacitor discharged with the constant current. Before reached the lower limit voltage, disconnected J3 and record the time t2, then measured voltage U2.

According to the principle of capacitance:

$$I = C\frac{dV_c}{dt}. \quad (1)$$

dV_c-Voltage variation caused by capacitor discharging; dt-time variation of discharging. From the formula 1, It could be obtained as the formula 2:

$$C = \frac{I\times(t_2 - t_1)}{U_1 - U_2}. \quad (2)$$

The changed voltage of Super-Capacitor:

$$dV = I\frac{dt}{C} + I_g R_{ES}. \quad (3)$$

R_{ES} is the equivalent series resistance. We can obtain the below formula by converting formula 3.

$$C = \frac{I_g dt}{dV - I_g R_{ES}}. \quad (4)$$

In the experiments, we charged the same Super-Capacitor using current of 10A, 20A, 30A, 50A, 70A, 90A, 100A, and measured the captaincies. It is shown in Figure

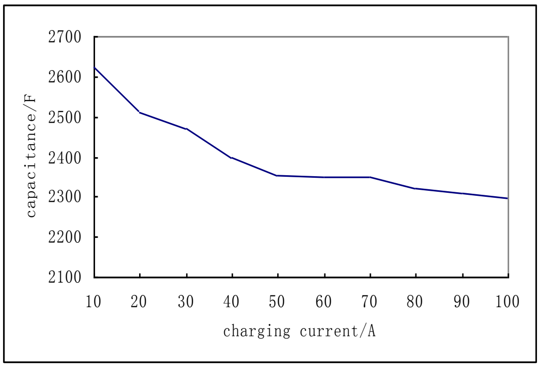

FIGURE 3 Changes of capacitance charging with constant current

The conversion efficiency and the effective capacity of super capacitor are affected by the most effective resistance and the charge and discharge current. The captaincies are small with large charging current.

In order to obtain the initial state of Super-Capacitor at the beginning of charging, we have established a constant current charging model of Super-Capacitor through the simulation software. The parameters are shown in table 1.

TABLE 1 The parameters of simulation

Input voltage/v	4
Charing current	50
Capacitance/F	100
ESL/µH	300
ESR/ohm	50

At a temperature of 25℃, we obtain the waveform of the simulation data shown in Figure

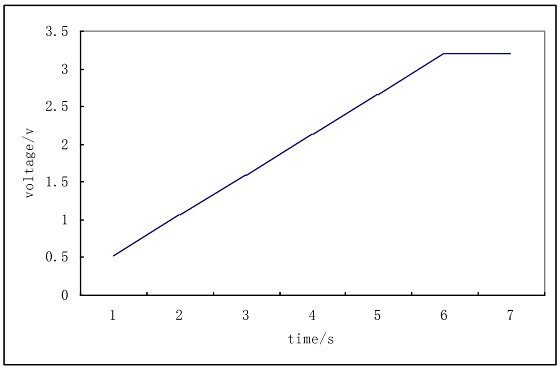

FIGURE 4 The waveform of charging with constant current

In Figure 4 ,the voltage grows linearly until it reach a constant value when it charged with large constant current .This proved that Super-Capacitor could be absorbed much energy in short time. We can convert charging with a constant voltage when the voltage is constant.

Because of the size and direction of current will change at the end of charging/discharging, We can measure the capacitor equivalent series resistance through the step method. The specific method is accurate to record the change of capacitor voltage when the size and direction of current changed.

$$ESR = \frac{U}{I}. \quad (5)$$

At room temperature, we use 2.7V as the upper limit voltage of the Super-Capacitor whose capacitance is 500F, and use 1.35v as the lower limit voltage. The Super-Capacitor was charged with constant current I=20A, 50A, 100A.

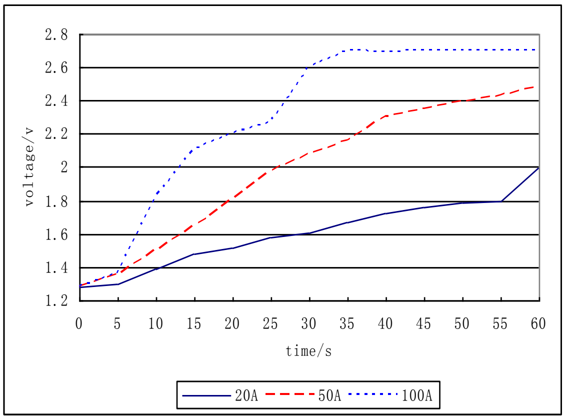

FIGURE 5 Voltage change of Super-Capacitor chared with constant current

It shows the variation of the charging process of Super-Capacitor voltage In Figure 5. It has a sinuate margin at the beginning and the end of charging. The charging voltage of Super capacitor change linearly. The voltage change quickly in the initial stage, and change gently in the middle, in the end it change quickly again. This proved: The time of Super-Capacitor charging fully is shorter when charging current get larger. It is mainly affected by the impact of the charging current and the equivalent series resistance. The effects of the two factors make the effective storage energy of super capacitor changes; it leads to lower effective energy storage with the increase of charging current.

3 Relation of the charging current and energy storage

We charge with constant current, if the capacitance of Super-Capacitor is constant, the voltage on capacitor will change with the charging time.

$$V_t = V_{\min} + I(R + \frac{t}{C}) . \tag{6}$$

The energy storage at the time of t can be expressed as:

$$E_t = \frac{Q_t V_t}{2} = \frac{C V_t^2}{2} = \frac{C[V_{\min} + I(R + \frac{t}{C})]^2}{2} . \tag{7}$$

In the formula 7: Qt – the amount of charge at any time;Vt – the voltage at any time; Vmin – the lower limit capacitance; I – the charging current.

The energy storage associated with charging current, Operating voltage range and the temperature of the environment. Figure 6 describes the function relationship between the change of Super-Capacitor energy storage and charging current in the working voltage and room temperature conditions. The energy storage changed a little charging with little current(less than 50A) and moderate current (50A～70A). But with the increase of the charge and discharge current (more than 70A), the energy storage declined rapidly. Super-Capacitor energy storage has a big constraint with large current and fast charging.

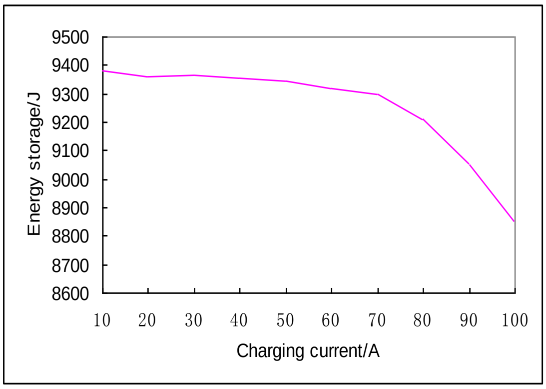

FIGURE 6 Charging current change to emerge storage

In the test of charging/discharging cycles, because of the influence of the Super-Capacitor equivalent resistance, the actual consumption w_k in the process of charging will be larger than capacitance E_t , The ratio between them is the charging efficiency of Super-Capacitor. The charging efficiency:

$$\eta = \frac{E_t}{w_k} = \frac{E_t}{\int_0^t Iu(t)dt} . \tag{8}$$

We test the charging efficiency with the charging current (10A, 20A, 30A, 50A, 60A,80A, 100A). The analysis has been shown in Figure 4.

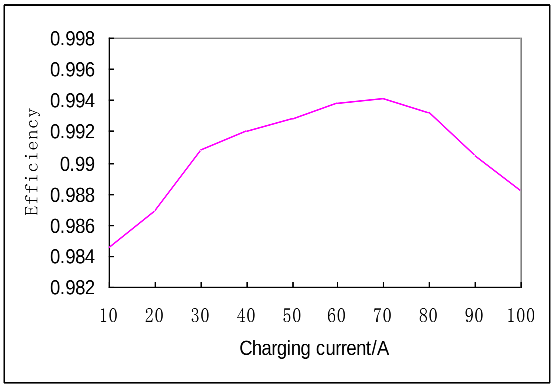

FIGURE 7 Relationship between the efficiency and current

In Figure 7, it describes the change of the relationship between charging efficiency with charging current in the constant current condition. The charging efficiency is lower when the current is small, it gradually increase with the increase of charging current. When the current charging procedure increased to a certain value, the charging efficiency would begin to decline. So in the choice of charging current, in order to meet the demand of users and achieve optimal configuration of Super-Capacitor, we should consider the charging time, energy storage and charging efficiency.

4 The relation between energy storage and leakage current

Before testing the leakage current,we should discharge the Super-Capacitor fully over one hour.We closed switch J1 and measured the voltage Uv of the resistance R1 when the voltage of capacitor reach to U_R.

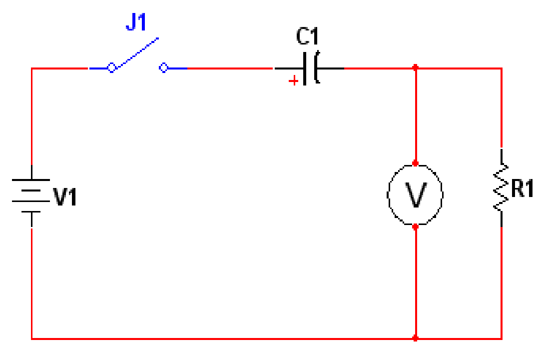

FIGURE 8 Circuit of leakage current testing

The calculation formula of leakage current:

$$I = \frac{U_v}{R} \times 10^3 mA . \tag{9}$$

The selected millivolt meter must be accurate, and must be calibrated before used. The resistance R1 is the most sophisticated resistance. The ripple voltage of DC power supply must be less than 3mv,this is very important. The line chart of leakage current testing is shown in Figure 9.

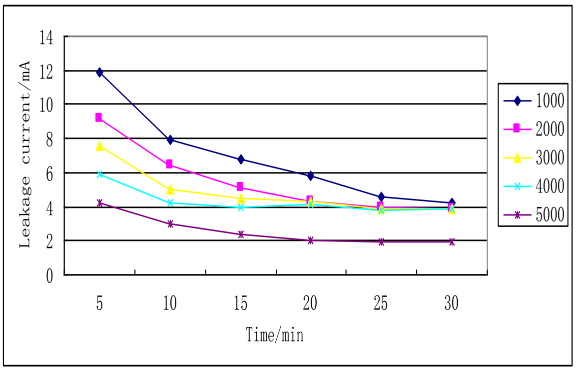

FIGURE 9 Line chart of leakage current testing

The relationship between leakage current and cycle index is shown in Figure 6. The leakage current is large at the beginning; with the test continued it reduced quickly. With the extension of time, the leakage current decreased and stabilized. After 1000 times cycles,the leakage current was kept in small range below 4mA, and 5000 times reduced to 2mA. This indicates that the performance is stable after the cycles.

5 Conclusions

Through the theoretical analysis and support of experimental data, we draw the following conclusions:

(1) The capacitance reduces with the increase of charging current.

(2) Small changes occur in the energy storage charging with small current. The energy storage will be limited with the increase of charging current.

(3) When the charging current is very small or very large, the charge efficiency is low. Moderate charging current have the highest efficiency.

(4) The leakage current is larger in the beginning, it will be stable after 5000 cycles.

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