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Study of Hybrid Super-capacitor

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Abstract - This paper presents the brief introduction for familiarity with hybrid super-capacitor. In the search of energy storage device with better performance scientist have recently launched a new type of device named as hybrid super-capacitor. This is the combination of electrochemical and double layer super-capacitor. It has an advantage of high energy density and high power density. Its working voltage is much greater than the existing super-capacitor(<3.5V), which makes it unique and helps to meet the requirements of high pulsed power system and high energy density like electric vehicle. Its equivalent circuit is studied, analyzed and simulated. Also various tests are carried out on hybrid super-capacitor experimentally and their results are discussed.

Key Words: energy storage device, energy density, power density, hybrid super-capacitor, pulsed power system.

1.INTRODUCTION

Now days the electricity generation by using renewable and clean energy resources such as solar energy and wind energy have made great progress. But all such energy sources have common problem that is how to store and release the energy, for better performance including efficiency. For this purpose, various alternatives are available, ex.-battery, fuel cell, flywheel battery and super-capacitor etc. Among all these equipment, super-capacitor which has advantage of high power density, high charging and discharging current levels, broad working temperature range and high durability for large no. of switching OFF/ON cycles. Hence these are preferred for many applications. Super-capacitor can be classified according to its working principle as Double layer Super-capacitor, Electrochemical super-capacitor and Hybrid super-capacitor. The hybrid super-capacitor means has two different types of electrodes. One of them is double layer super-capacitor material such as active carbon; the other is electrochemical-super-capacitor material such as ruthenium dioxide. This kind of super-capacitor includes the advantages of double layer super-capacitor and electrochemical-super-capacitor, so it can be employed in high energy and power density demand systems. The general needs of super-capacitors are high working voltage, big capacitance and low resistance for pulse power supply applications, especially for the pulsed power supply of electromagnetic launch system applications. However the working voltage of existing super-capacitors is very low (<3.5V), which has restricted its further applications. To meet the requirements of high voltage, conventionally engineers connects number of super-capacitors in series. But the total capacitance of energy storage device decreases, and the inner resistance increases. Based on the high working voltage of electrolytic capacitor the concept of hybrid super-capacitor was proposed.

2. DESIGN OF HYBRID SUPER-CAPACITOR

The hybrid super-capacitor composed of anode of electrolytic capacitor, cathode of electrochemical capacitor (battery) and electrolyte solution. That means its positive electrode's material is $Ni(OH)_2$ and the negative electrode is active carbon, the electrolyte is KOH aqueous electrolyte. The hybrid super-capacitor unit is assembled as shown in figure1.It is shown that the most voltage drops at the dielectric layer, and the voltage at the separator/electrolyte and cathode is very low. Therefore, the tolerant voltage of the anode dielectric layer determines the hybrid super-capacitor working voltage. Its basic physical structure is comprised of two electrodes, electrolyte, separator and current collector. So the integral equivalent circuit model can be built by incorporating each component's model.

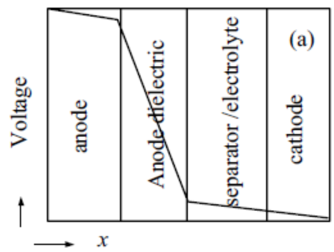


Fig -1: Internal structure and voltage distribution of the hybrid super-capacitor

3. EQUIVALENT CIRCUIT MODEL OF HYBRID SUPER-CAPACITOR

The hybrid super-capacitor consists of the two electrodes in which the negative electrode is identical with the Electric double layer capacitor and the positive one is similar to the battery. Reference [3] shows a simple resistive capacitive equivalent circuit model of the electric double layer capacitor, which is shown in Fig. 2. And the equivalent circuit model of the battery, which is shown in Fig. 4.

3.1 Positive Electrode

During the process of charging or discharging phase the chemical reaction will take place between the positive electrode and the electrolyte. And this process abides by the Faraday's Law. When Faraday electric charge migration occurs, the quantity of charge q has the functional relation with the electrode's potential Φ, and it can be measured by $dq/d\Phi$, which equals to a capacitor called electrolytic capacitor. According to this principle, the positive electrode can be modelled as a parallel circuit of a resistor and a capacitor, which is shown in Figure 2.

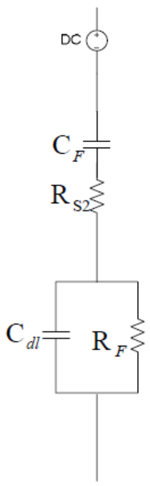


Fig -2: Equivalent circuit model for positive electrode

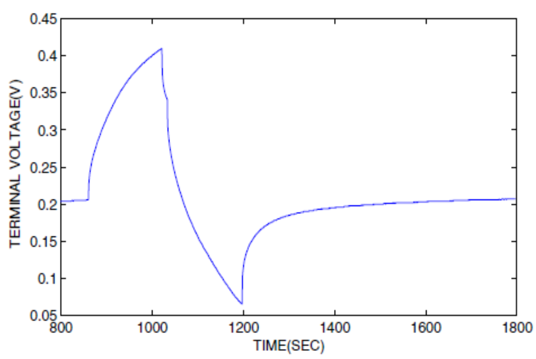


Fig -3: Terminal voltage of the positive electrode

3.2 Negative Electrode

As to the negative electrode, there is no chemical reaction occurring during the charging or discharging phase, so it can be a simply regarded as an ideal polarized electrode, which means its equivalent circuit is a pure capacitor which is shown in figure 4.

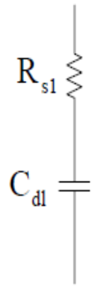


Fig -4: Equivalent circuit model for negative electrode

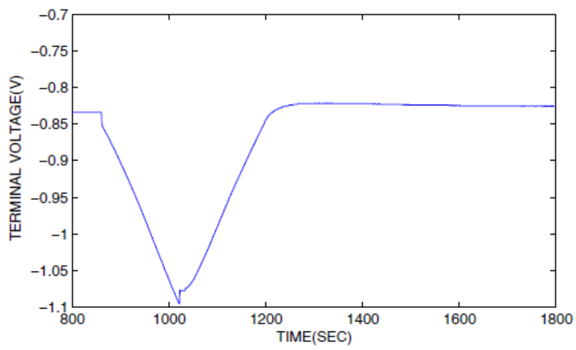


Fig -5: Terminal voltage of the negative electrode

Based on physical reasoning, the two electrodes of the asymmetric hybrid super-capacitor are connected in series. So the equivalent circuit model of the asymmetric hybrid super- capacitor can be achieved by connecting the positive equivalent circuit model with the negative equivalent circuit model in series as shown in figure 6.

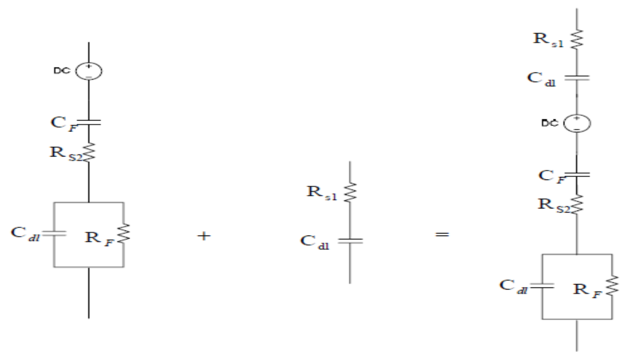


Fig -6: Forming of equivalent circuit model of hybrid super-capacitor

At last, a simplified equivalent circuit model of hybrid super-capacitor is presented based on physical reasoning, which is shown in Fig. 7.

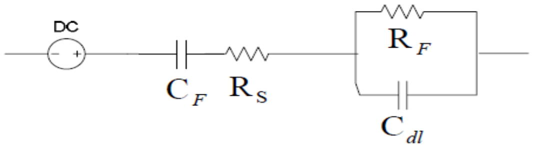


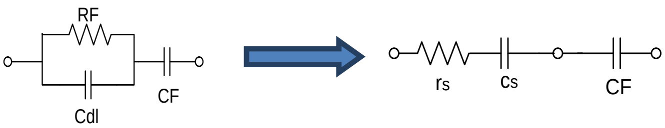
Fig -3: Simplified equivalent circuit model for hybrid super-capacitor

The parameters of equivalent circuit are taken from reference [4]

Table -1: Parameters of equivalent circuit

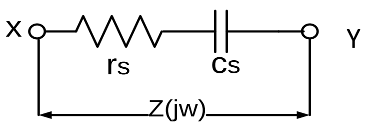
PARAMETER	C	R_S	C_{dl}	R_F
3500F AHS	4993	0.004	4222	0.01

According to network theory any equivalent parallel combination can be expressed into its equivalent series combination. RF, C_{dl} expressed in terms of r_s and c_s



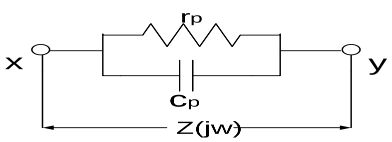
$$\frac{1}{3500} = \frac{1}{4993} + \frac{1}{C_s}$$

$$C_s = 11695$$



$$Z(jw) = r_s + \frac{1}{jwC_s}$$

$$= r_s - \frac{j}{wC_s}$$



$$\frac{1}{Z(jw)} = \frac{1}{r_p} + jwC_p$$

$$= \frac{1 + jwr_pc_p}{r_p}$$

$$Z(jw) = \frac{r_p}{1 + jwr_pc_p}$$

$$= r_p \times \frac{1 - jwr_pC_p}{1 + w^2 r_p{}^2 C_p{}^2}$$

$$= \frac{r_p}{1 + w^2 C_p{}^2 r_p{}^2} \times \left(1 - jwr_pc_p\right)$$

On comparing we get,

$$r_s = \frac{r_p}{1 + w^2 C_p{}^2 r_p{}^2}$$

$$C_s = \frac{1}{w^2 r_p C_p}$$

$$11695 = \frac{1}{w^2 \times 0.01 \times 4222}$$

$$w = 1.42 \times 10^{-3}$$

$$f = \frac{1.48 \times 10^{-3}}{6.28}$$

$$= 0.226\ milliHz$$

After the calculation it can be concluded that the value found match at very low frequency which is nearly equal to DC.

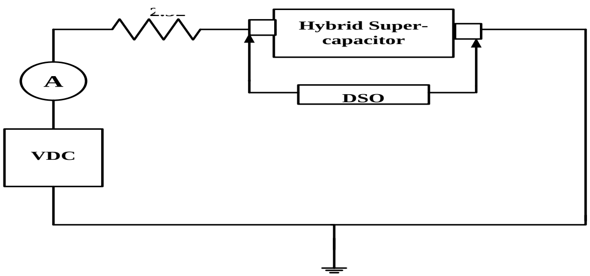
4. THE VCAP8000 HYBRID SUPER-CAPACITOR

The super-capacitor used in this experiment is Lanzar VCAP8000 80Farad, 16Volts hybrid super-capacitor. Its working voltage is 19V DC and its surge voltage limit is 24V DC. Its equivalent series resistance is 0.0015Ω at 25°C. Its outer case is made up of chrome plastic and has the blue flashing LED lights. It has the 4 digits blue light display DV voltage meter that can measure 0.1DCV range. Also it has reverse pole connection buzz warning function. If the capacitor is connected wrongly by reversing the positive and negative wires during the installation process the PCB will issue a noise to give warning.

Fig -7: VCAP8000 Hybrid Super-capacitor

5.HYBRID SUPER-CAPACITOR EVALUATION STATION

The author designed and fabricated an evaluation station for the charging of hybrid super-capacitor as shown in fig.8 and fig.9. The hybrid super-capacitor is charge with the help of variable DC source. Charging resistance is connected in series with hybrid super-capacitor to protect the device from the inrush current. Digital storage oscilloscope (DSO) is connected across the device to see the charging voltage characteristics.



. **Fig -8**: Hybrid super-capacitor charging block diagram

Fig -9:. Hybrid super-capacitor evaluation station

6. EXPERIMENTAL RESULT

Fig.10 shows the curve of charging Hybrid Super-capacitor at 50Ω resistance. The time requires to charge Hybrid Super-capacitor is around 30 min at 0.3A initial current which is very less. As we minimize the value of resistance, the time necessitate to charge the Super-capacitor is also reduces.

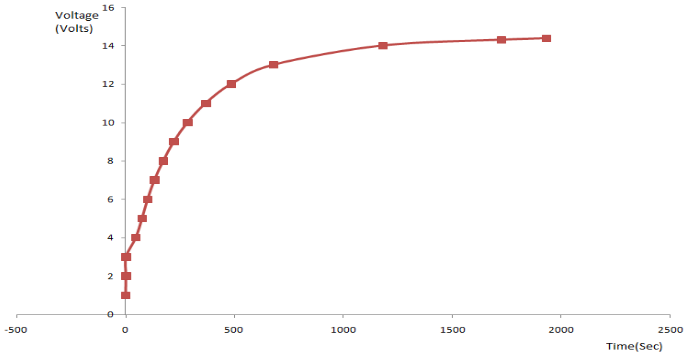


Chart -1: Hybrid super-capacitor charge profile

Meanwhile author also tried to simulate the equivalent circuit of hybrid super-capacitor and the results found are as shown in fig.11.

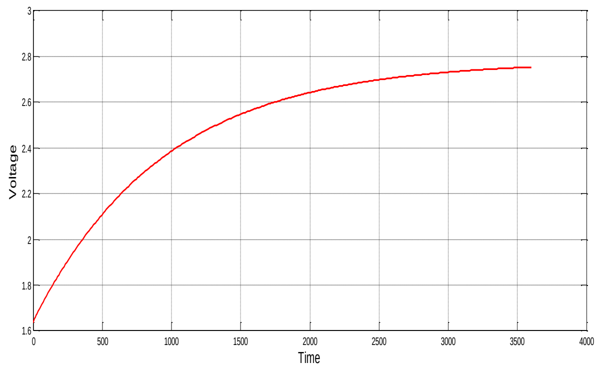


Chart -2: Simulation results of charging of hybrid Super-capacitor.

7. DISCUSSIONS AND CONCLUSION

In this study we can conclude that hybrid super-capacitor has the fast charging and discharging characteristics. Also its high voltage function makes it useful for the high voltage applications like electric vehicle. In our future work . It is also intended to learn some additional aspects including application of hybrid super-capacitor.

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BIOGRAPHIE

Neha Denge is a research scholar in G. H. Raisoni College of Engineering with the specialization in Integrated Power System.