Comparison of Charging Processes of Ultra-capacitor and Hybrid Ultra-capacitor Controlled by PWM Technique

[1]Pratik Dhabe, [2]Dr. S. G. Tarnekar

Department of Electrical Engineering
G. H. Raisoni College of Engineering
Nagpur, India

***Abstract*–Ultrcapacitor (UC) is known for large values of capacitance, high power density, high energy density and fast charging. UC is used in many industrial applications as a reliable storage device. The launching of Hybrid Ultracapacitor (HUC) has providedachoice between UC and HUC. The HUC has electrodes of distinct characteristics. One of its electrodes is made up of electrostatic type of material and the other is made up of electrochemical type of material. This paper is aimed at comparing the charging characteristics of UC and HUC. This enables the design engineer to select one of these, application-wise, considering technical as well as economic aspects. The charging circuits for UC and HUC are simulated using MATLAB. Also the charging circuit model using PWM technique is prepared for charging UC and HUC.**

***Indexterms* –Ultracapacitor, Hybrid Ultracapacitor, charging and discharging rate, energy density, PWM technique.**

I. Introduction

As the conventional fossil fuels are on the verge of depletion, electricity is being generated using renewable energy sources like solar, wind, hydro and geo-thermal. However, all these encounter a common problem of a reliable and efficient storage device. Advanced flywheel, battery, and ultracapacitorare some of the popular storage-devices. Out of these, the ultracapacitor has the advantage of large capacitance, high energy density, high power density and faster charging operation. This makes the ultracapacitor an obvious choice of the engineers in large number of applications.

Many industries have employed UC as a reliable storage device owing to its advantages over other storage devices. However, the launching of Hybrid Ultracapacitor has opened up another choice before the design engineers. HUC has a peculiar feature of having its electrodes made up of different materials. As a result, HUC has the combined benefits of electrostatic and electrochemical type of capacitors. The Ultracapacitor has the limitation on its maximum working voltage due to thebreakdown strength of the electrolyte. Thus, to use an UC for high voltage applications, large numbers of units have to be connected in series. This, however, increases the overall series resistance of the device and decreases the equivalent capacitance. HUC can be manufactured for high voltage applications and thus there is no need to connect many units in series.

II. Design of the Hybrid ultracapacitor

Due to the limitation on the breakdown potential of the electrolyte, the maximum working voltage of the UC is usually less than 3 V. However, many applications in electric vehicles and launching systems require high voltage. In order to meet the high voltage demands of such applications, the HUC was launched in 2015. The HUC combines anode of electrolytic capacitors and cathode of electrochemical capacitors.Hence, it has the features of high working voltage of electrolytic capacitor, and high specific capacitance and high energy density of electrochemical capacitor. Due to large capacitance and high working voltage, HUC can meet the demands of pulse power systems. Compared with the UC, the working voltage of HUC is obviously very high. Hence, the HUC can cater the needs of high voltage applications.

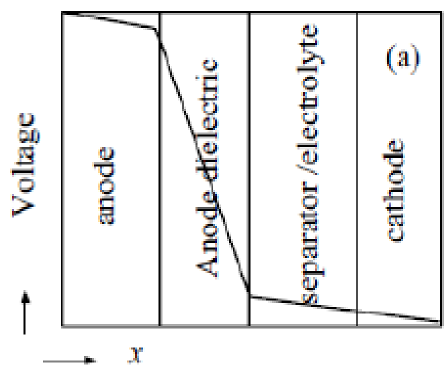

Fig.1. Internal voltage distribution of the Hybrid ultracapacitor

The internal voltage distribution of the HUC is as shown in figure 1 above [2]. It is observed that the maximum voltage drop takes place at the dielectric layer and the voltage at the separator and cathode is very low.

Since the working voltage of the HUC is very high, large number of units of HUC can be connected in parallel to form an energy storage device of high density. The parallel connection of HUC units raises the capacitance of the array and decreases the equivalent series resistance. On the contrary, the UC units have to be connected in series to form an energy storage device of high voltage due to its small value of working voltage. The series connection of UC units decreases the overall capacitance and increases the effective series resistance. This is not conducive for an efficient energy storage device. Hence, it is beneficial to adopt high voltage HUC for high voltage and pulse power applications.

III. Experiment

A. Experimental setup for charging of UC / HUC

The block diagram for the charging of UC / HUC is shown below in figure 2. The capacitor is charged using a variable DC source. The resistance is connected in series so as to prevent the device from the large value of inrush current.

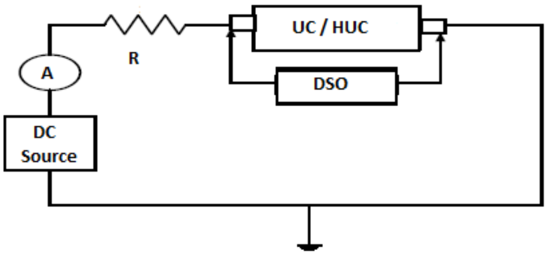

Fig.2. Block diagram for charging of UC / HUC

B. Charging of UC Using Constant Current Method

The UC in this experiment is charged using constant current method. The constant current IC 731 is used to generate a constant current of 1 A. The figure 3 below shows the experimental setup for charging of UC using IC 731.

Fig.3. Charging of UC using constant current method

The experimental result shows that the UC takes 14 minutes to get charged to a value of 14 V at the constant current input of 1 A.

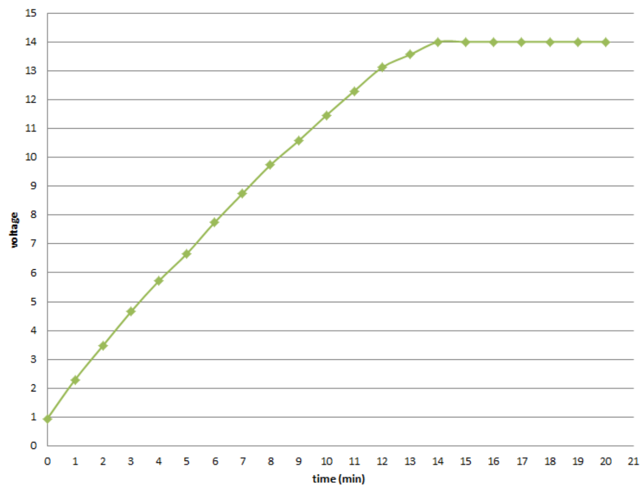

Fig.4. Charging characteristic of UC using constant current method

The figure 4 above shows the charging characteristics of UC obtained from the experiment. It is observed that the UC starts charging from an initially discharged condition and takes 14 minutes to get completely charged. After 14 minutes, the voltage remains constant indicating that the device has reached its maximum voltage.

B. Charging of HUC Using Constant Current Method

The figure 5 below shows the experimental setup for charging of HUC at a constant current of 1 A using a constant current IC 731.

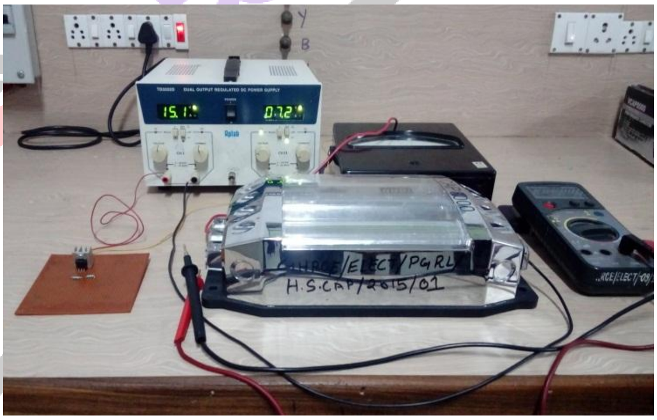

Fig.5. Charging of HUC using constant current method

The experimental result shows that the HUC charges to 14 Volts in just 3 minutes at the constant current input of 1 A.

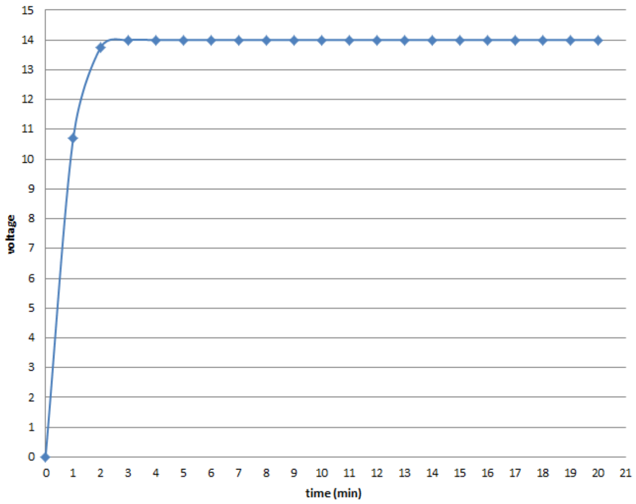

Fig.6. Charging characteristic of HUC using constant current method

The figure 6 above shows the charging characteristics of HUC obtained from the experiment. It is seen that the HUC starts charging from a discharged state and is charged to 14 V in 3 minutes. The charging profile remains constant after 3 minutes.

C. Charging of UC Using PWM Technique

The UC in this experiment is charged with the help of PWM technique. With the help of PWM technique, the duty ratio can be varied so as to control the charging current of the device. By varying the duty ratio the charging rate of UC can be controlled. The boost converter is used to boost the voltage from battery to quickly charge the UC. The figure 7 below shows the experimental setup for charging of UC using PWM technique.

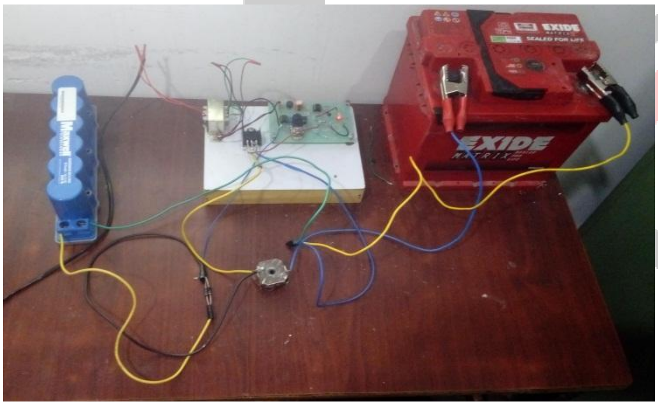

Fig.7. Charging of UC using PWM technique

The figure 8 below shows the charging characteristics of UC when charged using PWM technique.

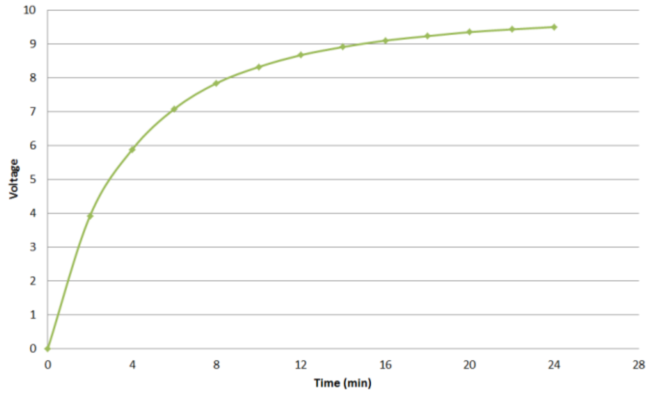

Fig.8. Charging characteristics of UC using PWM technique

The UC takes 24 minutes to charge up to a value of 9.5 V at a duty ratio of 50%.

D. Charging of HUC Using PWM Technique

The figure 9 below shows the experimental setup for charging of HUC using PWM technique. The duty ratio can be varied to control the charging current and the charging rate of the device.

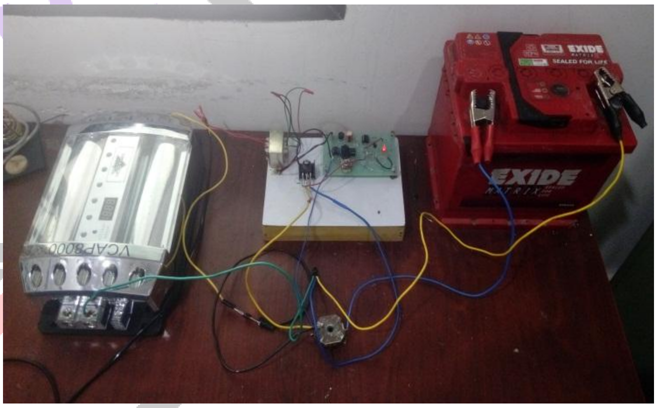

Fig.9. Charging of HUC using PWM technique

The figure 10 below shows the charging characteristics of HUC using PWM technique at duty ratio of 50%.

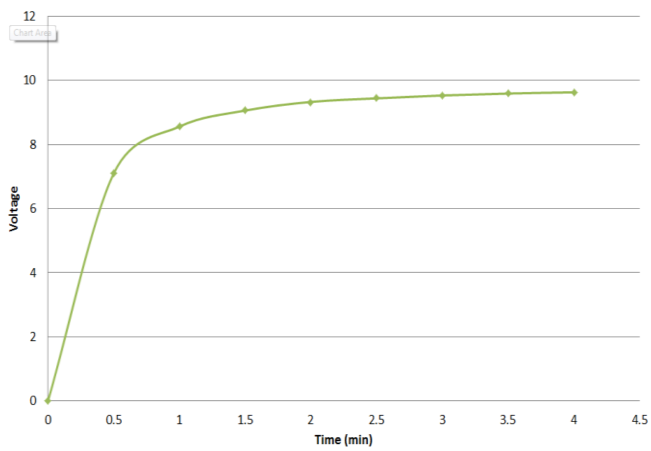

Fig.10. Charging characteristics of HUC using PWM technique

The HUC takes only 4.5 minutes to charge up to 9.5 V using PWM technique at duty ratio of 50%.

E. Self- discharge of the Hybrid Ultracapacitor

The self-discharge of HUC is of significance since it determines the ability of the device to flash charge other capacitor. In this experiment, the HUC is charged to 14 volts using constant current method and is left alone for self-discharge.

Figure 11 below shows the self-discharge curve of HUC. It is observed that the HUC has linear self-discharge characteristics. The HUC can be discharged faster and has better discharge efficacy.

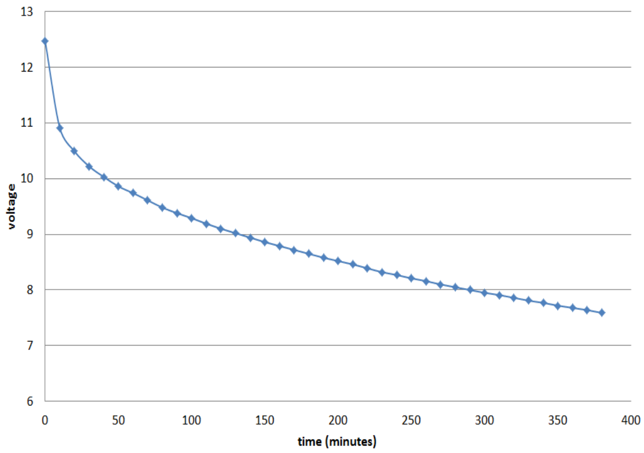

Fig.11. Self-discharge characteristic of HUC

Many cold countries employ batteries to warm the coagulated fuel during winters. Since, HUC has a good discharge characteristic, it can be used to liquefy the coagulated fuel.

IV. Results And Discussion

From the experimental studies it is observed that the HUC has a quicker charging ability and has high energy density and power density. The figure 12 below shows the comparison of the charging times of UC and HUC when charged at constant current of 1 A.

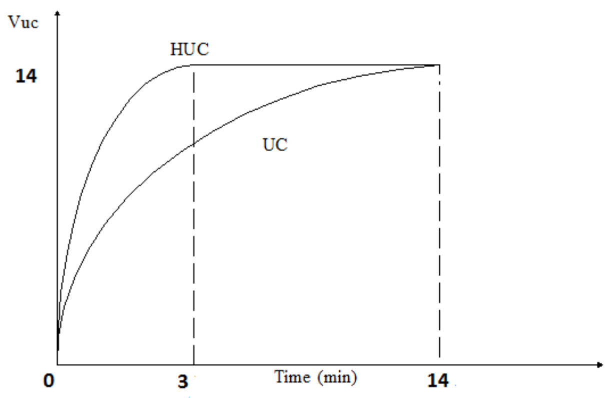

Fig.12. Comparison of charging characteristics of UC and HUC using constant current method

It is seen from the above graph that the HUC has faster charging rate as compared to the UC. The HUC takes 3 minutes to charge up to 14 V as against 14 minutes taken by the UC at the constant current input of 1 A..

TABLE I

Time Required By UC and HUC to Charge

DUTY RATIO	Time required in minutes to charge the UC	Time required in minutes to charge the HUC
25%	22.5	5
50%	22	4
75%	21.5	3

The above table shows the comparative study of the charging rates of UC and HUC when charged at different duty ratios using PWM technique. HUC shows a positive response to the change in duty ratio and charges quicker that the UC.This makes the HUC an obvious choice ahead of the UC in high energy density and high voltage pulse power applications

V. Conclusion

This paper presents the experimental results of the charging characteristics of UC and HUC. It can be noticed from the comparison that the HUC has faster charging rate and has high energy density and high power density. Since the HUC has a high working voltage unlike UC, there is no need to connect large number of units in series. A single unit of HUC is sufficient to cater the needs of high voltage and pulse power applications.

Due to the faster charging rate of HUC, it can be used at charging stations to flash charge the ultracapacitor driven city buses in communist countries. Also, the HUC can be used in place of batteries in cold countries to warm the fuel and engine during winters. This, in turn, will enhance the efficiency of the battery. The HUC has high capacitance and high charge-discharge efficiency.

References

[1] Yonghua Cheng, “Assessments of energy capacity and energy losses of supercapacitors in fast charging-discharging cycles” IEEE Transactions on energy conversion, vol.25, NO. 1, MARCH 2010.

[2] Zhang Li, Song Jin-yan, Wang Ning, “High voltage super-capacitors for energy storage devices applications” IEEE Transaction, pp1-4, 2008.

[3] Ji-Yan Zou, Li Zhang, and Jin-Yan Song, “Development of the 40V Hybrid Super-Capacitor Unit” *IEEE Transaction on Magnetics*, Vol. 41, pp- 197 – 201, January 2005.

[4] Dr. S. G. Tarnekar, Neha S. Denge, “Performance evaluation of hybrid super-capacitor module for energy storage applications” IJEREEE Vol.2, Issue 3, March 2016.