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Development of Three Electrode System for Optimizing the Parameters of Hybrid Capacitor

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Abstract

Objectives: To fabricate the hybrid capacitor by novel configuration and implementation of prototypes with hybrid capacitor making processes at laboratory. The purpose of this investigation is to study the effect of novel configuration in comparison with conventional two electrodes. Many researchers have concentrated on the materials used for making hybrid capacitors and very little research is available on configuration of electrodes used for hybrid capacitor which is important for further development but unfocused area. Methods: The prototypes were made by simple mixture and loading technique of electrode material. Polyethylene sheets were used as separators to prevent the short circuit between the electrode and aqueous potassium sulphate solution used as electrolyte. Statistical Analysis: The charging-discharging cycle analysis gives parameters of hybrid capacitor i.e., energy density, power density, internal resistance, specific capacitance for developed prototypes. The parameters for developed prototypes and conventional two electrode hybrid capacitor prototypes were observed. Comparative analysis for various parameters of developed prototypes was conducted and readings noted down. Findings: From charge-discharge test of hybrid capacitor it was concluded that the higher values for energy density, power density and specific capacitance can be obtained by using novel configuration of electrodes. The graphical analysis from charge-discharge test demonstrated decrease in internal resistance. It was also found that in case of hybrid capacitor with three electrodes with extra non faradic systems all the parameters are higher than conventional hybrid capacitor and hybrid capacitor three electrode system with extra faradic. Applications: Hybrid capacitors have high energy density compared to super-capacitors with better long term cycling ability. Due these additional advantages hybrid capacitors have attractive applications where high current pulses are repeatedly required. This technology is yet coming up to develop high grade hybrid capacitor which may replace batteries or may work along with the batteries in near future.

Keywords: Electrical Energy Storage, Electrodes, Electrolyte, Hybrid Capacitor, Parameters

1. Introduction

Supercapacitor or ultracapacitor is a step ahead for capacitor technology and new electrical energy storage device which is under development stage. Present supercapacitor technology is suitable for electronic devices, portable hand tools, data backup system, automotive system etc. The working of Supercapacitor is based on charge storage by charging of Supercapacitor electrodes separated by ion permeable separator in electrolyte medium[1–3]. Charge storage in Supercapacitor is psedocapacitive and further utilization of this pseducapacitive phenomenon leads to increase the capacitance value to higher range[4]. Various materials are available which exhibit psedocapacitive properties like Activated carbons, conducting polymers, metal oxides etc. Researchers have done various experiments to improve the capacitance and energy density of Supercapacitor. Results of these experimentations conclude that use of metal oxide exhibits higher capacitance, good electrical conductivity along with excellent electrochemical reversibility and long cycle life[5,6].

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Present state is the development stage for capacitor technology. Various characteristic such as energy density, power density, specific capacitance, internal resistance etc. are required to be improved. Very few companies are present around the globe who manufactures these capacitors[7]. Material used for making such capacitor is costly. For commercialization of this capacitor lower cost alternative material must be used. Scientist BE Convey and scientist Andrew Burke had given significant contribution in the field of ultracapacitor[1–8]. Various researchers have also given their contribution in the development ultracapacitor by introducing new design, shapes and model prototype.

Trials and work have been carried out with variety of Activated carbon and metal oxides for studying impacts of these materials on characteristics of ultracapacitor[9]. Improved parameters are achieved by applying recent technology of material mixing like ball milling, ultra sonic mixing etc[10]. Researchers concentrate on different alternatives for these materials along with various important characteristic unaffected such as energy density, power density and specific capacitance[11].

Materials used for construction of ultracapacitor, finding alternative material which will be economical, efficient with better charge storage properties and application of new upcoming technology for mixing and binding of materials are recent research areas in the field of ultracapacitor[12–15]. Variation of electrode in construction of ultracapacitor is the area which is not focused by researcher although it is one the important area. Present paper includes this unfocused area for further development.

Symmetric two electrode capacitors built with metal oxide and activated carbon composite material had given better capacitance profile than the electrical double layer capacitor with two symmetrical activated carbon electrodes. The combination of two different electrodes made i.e., one electrode is faradic and other electrode is non faradic which demonstrated better energy density and capacitance profile. This type of configuration is also known as hybrid capacitor[16]. In Hybrid capacitor combination of faradic and non faradic electrodes are producing higher energy density and capacitance. Faradic electrode is made of composite material i.e. metal oxide mixed with activated carbon at 1:1 proportion and non-faradic electrode composed of activated carbon only. A conventional hybrid capacitor composed of faradic and non faradic electrode. Variation in electrodes of hybrid capacitor is the area which is not focused by many researchers is taken into consideration for further development[17,18].

The present study tries to address this issue and optimize the parameters of hybrid capacitor by introducing a new concept of three electrode system. Hybrid capacitors with innovative design of three electrode system have been implemented in this study. This paper is organized as; Section 2 is about experiments for development of hybrid capacitor Section 3 consist of Results and Discussion and Section 4 consist of conclusions.

2. Experimentation

For development of a conventional two electrode hybrid capacitor, commercially available wire mesh SS304 is used as a current collecting element. Electrodes of hybrid capacitor were made by cutting wire mesh SS304 into rectangular shape of length 3 cm and breadth 1 cm. All the electrodes of hybrid capacitor were cut into the same size in this experimentation. Effective loading area of rectangular electrode calculated as length*breadth i.e., here 3 cm*1 cm = 3 cm^2.

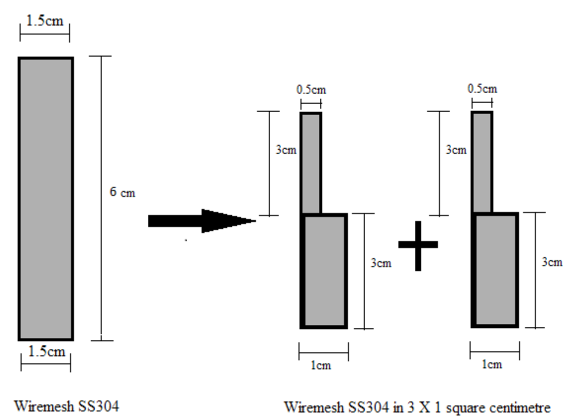

Figure 1. Effective loading area of electrode.

2.1 Development of a Conventional Hybrid Capacitor

A conventional hybrid capacitor is made of two electrodes of dissimilar materials. One electrode is faradic and other is non faradic electrode[9]. To make faradic electrode, slurry of composite material i.e., activated carbon and metal oxide is used as electrode material. In this experimental work slurry of vulcun XC–72R commercially available activated carbon and manganese oxide is used in the ratio 1:1 was made by using isopropyl alcohol. Slurry of composite material was loaded on the rectangular wire mesh at 20 mg/cm^2 and left for being settled and drying for one day. For making non faradic electrode slurry of activated carbon vulcun XC-72R was made with isopropyl alcohol and loaded on rectangular wire mesh. Both faradic and non faradic electrodes were left for setting and drying purpose[15,16].

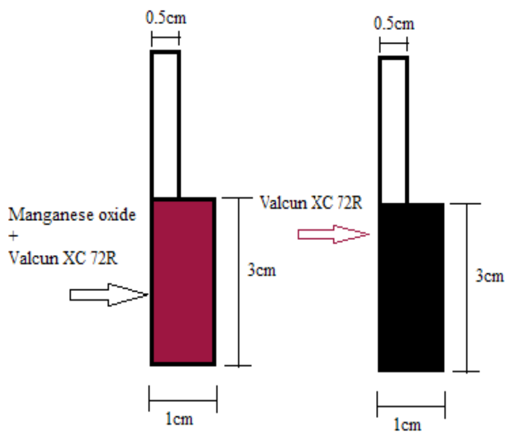

Figure 2. Shape and constructional details for hybrid capacitor electrodes (Faradic and non-faradic electrode respectively).

The electrodes were sandwiched in between polyethylene sheets according to the type of hybrid capacitor to be constructed. Polyethylene sheets are acting as separator to prevent short circuit between the electrodes. These sheets are stuck with epoxy resin and compacted to remove air pockets. These types of construction methods were used by researchers in their work[17]. The developed hybrid capacitor is kept inside a beaker containing 0.6 molar potassium sulphate electrolyte solution then compared on the basis of various parameters such as power density, energy density, internal resistance and specific capacitance. These parameters of developed hybrid capacitor were tested by charging and discharging of this capacitor at a fixed voltage of 2.2 V DC.

2.2 Development of Hybrid Capacitor with Three Electrode System

The hybrid capacitor with three electrode system was developed similar to the conventional two electrode hybrid capacitor using wire mesh SS304 is used as a current collecting element. Faradic and non faradic electrodes used for capacitor development was having same area and shape. As explained in the earlier section, the hybrid capacitor with three electrode system was assembled by sandwiching them in between poly ethylene sheets. The electrodes and the polyethylene sheets were kept in place with the help of epoxy resin and the assembled hybrid capacitor with three electrode system was immersed in 0.6 molar potassium sulphate aqueous electrolyte solution. The developed hybrid capacitor then tested for charging and discharging at 2.2 V DC. Table 1 gives the details about the configuration and variation done for the development of hybrid capacitor with three electrode system.

Table 1. Details of electrodes used for experimentation

No. and type of electrodes used for making hybrid capacitor	Hybrid capacitor configuration		
	Dimension	Effective Area	Type
2 Electrode 1 Faradic, 1 Non faradic	l=3cm, b=1cm	3cm2	Conventional hybrid capacitor
3 Electrode 2 Faradic, 1 Non faradic	l=3cm, b=1cm	6cm2	Hybrid capacitor with extra positive
3 Electrode 1 Faradic, 2 Non faradic	l=3cm, b=1cm	6cm2	Hybrid capacitor with extra negative

The comparison of developed three electrode system hybrid capacitor is done by considering a conventional hybrid capacitor as a reference. Some photographs of developed hybrid capacitor are given as below.

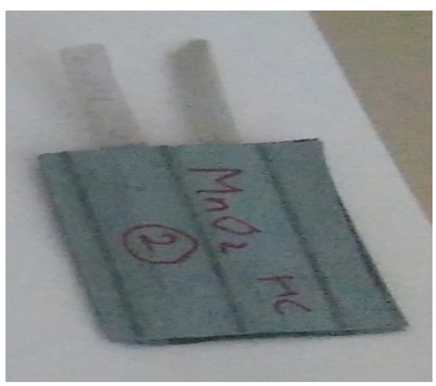

Figure 3. Conventional two electrode hybrid capacitor.

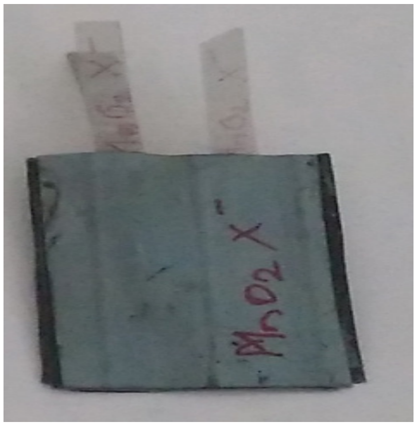

Figure 4. Three electrode hybrid capacitor with extra non-faradic (negative) electrode.

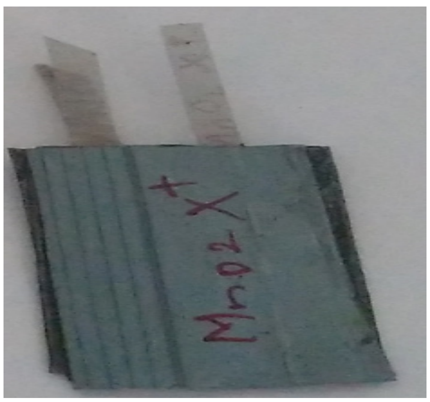

Figure 5. Three electrode hybrid capacitor with extra faradic (Positive) electrode.

3. Results and Discussion

The faradic electrodes were used as positive and non faradic electrodes were used as negative then tested for the various parameters like power density, energy density, equivalent series resistance and specific capacitance. Figures 6 to 10 illustrate the effect of three electrode systems in comparison with conventional hybrid capacitor on various parameters such as power density, energy density, internal resistance and specific capacitance. Also effect of faradic and non faradic electrode on the three electrode system can be seen.

3.1 Power Density of Developed Hybrid Capacitor Prototypes

Effect on power density is analysed by experimentation and trials on developed hybrid capacitor prototype and results are represented in graphical form. Also effect of faradic and non faradic electrode on the three electrode system can be seen.

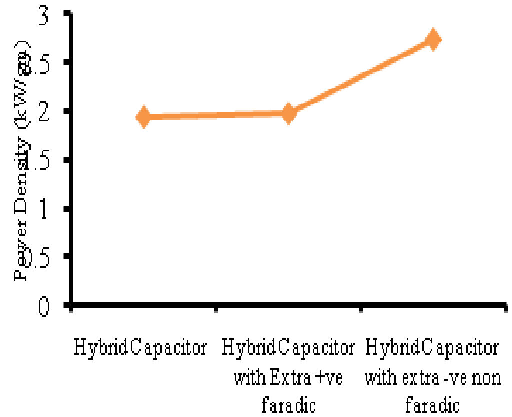

Figure 6. Power densities of developed hybrid capacitor prototypes.

It can be clearly seen from Figure 6 that energy density of three electrode hybrid capacitor with extra negative i.e., non-faradic electrode is more than conventional hybrid capacitor and hybrid capacitor with extra positive electrode system.

3.2 Energy Density of Developed Hybrid Capacitor Prototypes

Effect on energy density is found by experimentation and trials on developed hybrid capacitor prototype samples and results are given in graphical form as below. Also effect of faradic and non faradic electrode on the three electrode system is studied.

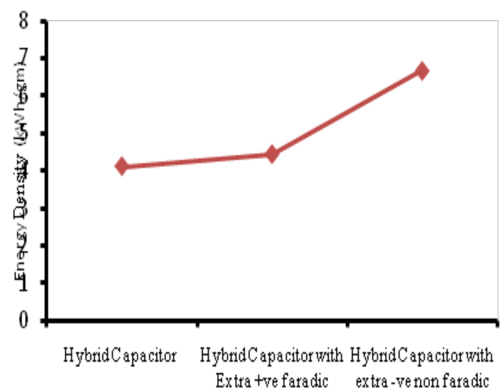

Figure 7. Energy densities of developed hybrid capacitor prototypes.

Figure 7 show that energy density for three electrode hybrid capacitor with extra negative is more than conventional hybrid capacitor and hybrid capacitor with extra positive electrode system.

3.3 Internal Resistance of Developed Hybrid Capacitor Prototypes

Effect on Internal resistance is studied by experimentation and trials on developed hybrid capacitor prototypes and results are as below in graphical form. Also effect of faradic and non faradic electrode on the three electrode system is analysed.

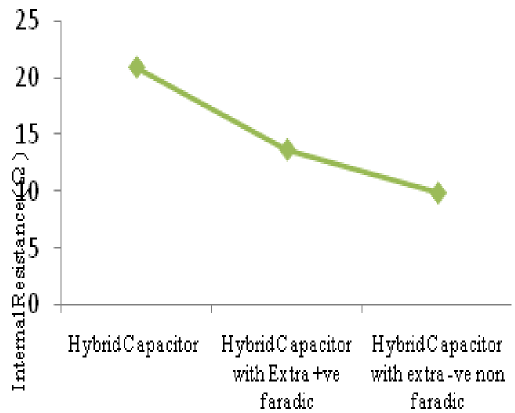

Figure 8. Internal Resistance of developed hybrid capacitor prototype.

From Figure 8 internal resistances for developed hybrid capacitor can be studied and this has given linear relation. Internal resistance for three electrode hybrid capacitor with extra negative electrode system is less than conventional hybrid capacitor and hybrid capacitor with extra positive electrode system.

3.4 Specific Capacitance (farads) of Developed Hybrid Capacitor Prototypes

Specific capacitance is analysed by experimentation and trials on developed hybrid capacitor prototype and results are as below. Also effect of faradic and non faradic electrode on the three electrode system is explored.

Figure 9 gives specific capacitance for developed hybrid capacitor prototypes. Specific capacitance for three electrode hybrid capacitor with extra electrode system is higher than conventional hybrid capacitor and hybrid capacitor with extra positive electrode system.

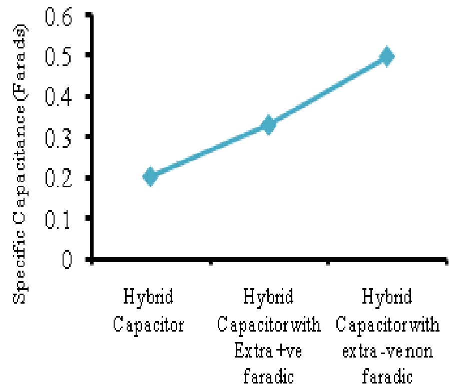

Figure 9. Specific capacitance of developed hybrid capacitor prototype (Farads).

3.5 Specific Capacitance (farads/gm) of Developed Hybrid Capacitor Prototypes

Specific capacitance in farads/gm for developed hybrid capacitor prototypes is shown. Specific capacitance in farads per gram is giving linear characteristic. Figure 10 shows linearly increased specific capacitance characteristic.

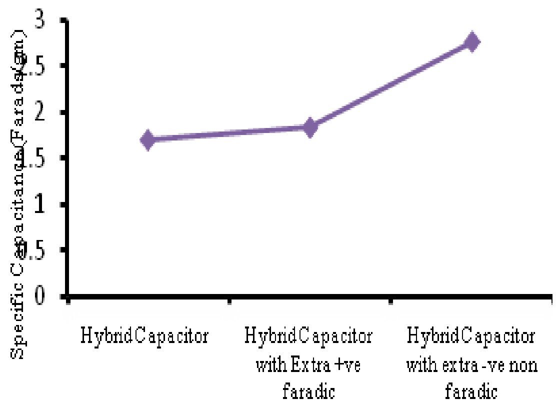

Figure 10. Specific capacitances for developed hybrid capacitor prototypes(Farads/gm).

From graphs (Figures 6-10) it can be seen that highest values of all the parameters can be obtained by implementing three electrode systems by using to non faradic electrode. Three electrode systems are giving better parameters than conventional two electrode system.

From Figure 8 it can be seen that the internal resistance is decreasing from two electrode hybrid capacitor to three electrode system hybrid capacitor so improved power density and energy density is achieved.

Table 2. Parameters of developed hybrid capacitor

Parameters of developed hybrid capacitor	Hybrid capacitor configuration		
	Conventional hybrid capacitor	Hybrid capacitor with extra positive	Hybrid capacitor with extra negative
Pulse current (mA)	64	64.8	82.36
Time consatant	4.25	4.5	4.9
Specific capacitance (farad/area)	0.067936	0.054981	0.082888

From Table 2 specific capacitance per area for developed hybrid capacitor prototypes are given. Specific capacitance for three electrode system with extra positive is less than other two type of hybrid capacitor. This is due to pseudo capacitive properties of faradic electrodes.

4. Conclusion

Energy storage is very important and super capacitor and hybrid capacitors will be future energy storage devices especially for pulse current requirements. Hybrid capacitor development is not matured. This technology is yet coming up so many researcher are working in laboratory to develop the high grade hybrid capacitor which may replace batteries or may work along with the batteries in near future.

The present study tries to optimize the parameters of a conventional hybrid capacitor by introducing an innovative concept of three electrode system. The optimized parameters of hybrid capacitor with three electrode system are obtained when the extra non faradic electrode is used.

It was found that in case of hybrid capacitor with three electrodes with extra non faradic systems all the parameters are higher than conventional hybrid capacitor and hybrid capacitor three electrode system with extra faradic. So best possible parameters can be obtained by development of such three electrode system and this system will help to boost the parameters of hybrid capacitor over conventional capacitor. These research results are very interesting in the perspective of development of hybrid capacitors and its practical application.

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