A

PROJECT REPORT

ON

DESIGNING AND SIMULATION OF ASYMMETRIC SUPERCAPACITOR BY USING BIOMASS MATERIALS

SUBMITTED IN PARITIAL FULFILLMENT OF THE

REQUIREMENT FO R THE DEGREE OF

BACHELOR OF ELECTRICAL ENGINEERING

SAVITRIBAI PHULE PUNE UNIVERSITY

BY

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UNDER THE GUIDANCE OF

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DEPARTMENT OF ELECTRICAL ENGINEERING

PES's MODERN COLLEGE OF ENGINEERING,

PUNE -05

Year: 2023-2024

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CERTIFICATE

This is to certify that the project entitled

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Has been carried out successfully by

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It is bonafied work carried out by them under supervision of Prof.- PROF. MRS. G. K. PALNITKAR and is approved for the partial fulfilment of requirement of Savitribai Phule Pune University , for the award of the Degree of Bachelor of Electrical Engineering.

Approved Date:

Prof. Dr. (Mrs.) N. R. Kulkarni — **Prof. Mrs. G. K. Palnitkar**

Head of Electrical Department — **Project Guide**

Signature of External Examiner

Date:

ACKNOWLEDGEMENT

It is said that knowledge is the gateway to success and to get the right knowledge, one requires a right teacher as we are eighth semester students of BE Electrical Engineering very well Know that without the right direction and guidance of our beloved professors, it might not have been possible to complete and present this Project report. It gives us great pleasure in having an opportunity to express a deep sense of gratitude to our principal, **Prof**. **Dr. (Mrs.) K.R. Joshi**, for providing us necessary facilities. We are also thankful to our HOD, **Prof**. **Dr. (Mrs.) N.R. Kulkarni** for her time to time guidance and support.

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We are also thankful to all the professors and staff members of the electrical department for the advice, suggestion and criticism.

Last but not the least we would like to thank all the unknown hands which made this Work directly or indirectly, a success.

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ABSTRACT

As the supercapacitors are emerging as energy storage devices and have gained much attention in recent years. Capacitor has high power density and battery has high energy density but the supercapacitor lies between both of them i.e. it consists of both high power density and high energy density, making them suitable for applications that require quick bursts of energy or high-power delivery.

Among the wide range of systems covered by this topic, low cost, environmental friendliness and high power provide MnO2 with great characteristics to be a competitive candidate. The present work reports asymmetric supercapacitor system using activated carbon made up from the biomass material as the negative electrode and the combination of activated carbon and manganese dioxide in 1:1 ratio as the positive electrode.

The modelling and designing of a supercapacitor featuring activated carbon electrodes derived from diverse biomass sources (Orange peels and Teak wood) and a polyethylene as a separator. The abstract consists of the essence of our research and the utilization of sustainable materials in energy storage devices.

Our simulations consists of electrostatics behaviour and performance characteristics of the supercapacitor, focus on the potential of biomass-based electrodes. The outcomes aim to contribute insights into environmentally friendly energy storage solutions and looking for further advancements in this domain.

A prototype of hardware is made by sandwiching the layer of separator (polyethylene sheet) inside activated carbon electrode. A mini-version of supercapacitor based on biomass material is used and tested.

Activated carbon is made by pyrolyzing the bio mass materials inside muffle furnace. There are three layers in which one is of polyethylene sheet and two are activated carbon electrode pasted on mesh sheet and two more polyethylene sheets are used to cover this supercapacitor and this complete model is dipped inside K2SO4 solution.

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CHAPTER 1

INTRODUCTION

Supercapacitors, also known as ultracapacitors, have been gaining attention in the energy storage market due to their unique characteristics such as high power density, long cycle life, and environmentally friendly disposal. The primary technology of supercapacitors relies on charging an electrical double layer at the interface between the electrode and electrolyte, where high surface area carbons are used. The main obstacle to the widespread use of supercapacitors is their high cost compared to batteries. The most expensive component of a supercapacitor is the electrode, and reducing its cost is essential for making the device commercially viable.

Activated carbon, derived from various carbonaceous precursors, is the most commonly used electrode material due to its high porosity and electrical conductivity. While activated carbon can be obtained from a wide range of carbonaceous precursors, lignocellulosic biomass is particularly promising. However, the use of biomass native to the Indian subcontinent as a precursor for activated carbon requires further investigation. Moreover, there is a lack of literature that optimizes the activation method of the precursor specifically for its application in supercapacitor electrodes.

In the initial stages of research, various biomass sources abundant in India were activated through pyrolysis in a nitrogen atmosphere. The resulting activated carbon was then used to fabricate supercapacitor electrodes, and their specific capacitance was evaluated. After extensive experimentation, teak wood were identified as the most suitable precursor. Further research was conducted to determine the optimal activation method and development process for supercapacitor electrodes using teak wood.

Supercapacitors are characterized by their long cycling life and high power density, offering promising application prospects in various fields. Generally, SCs can be categorized into two main types: electric double layer capacitors (EDLCs) and Pseudo capacitors. The capacitance of EDLCs primarily stems from the adsorption of anions and cations on or near the electrode/electrolyte interface, and this phenomenon is closely linked to the surface area of the electrode material. Porous carbon materials, such as activated carbon, carbon nanotubes, carbon nanofibers, and graphene, are commonly employed electrode materials for EDLCs. These carbon materials exhibit high specific surface area and good conductivity, contributing to enhanced specific capacitance. Despite the superior conductivity and surface area of graphene and carbon nanotubes compared to other carbon materials, activated carbon has emerged as an ideal electrode material for EDLCs due to its ease of processing, lower cost, adjustable surface area, relatively inert electrochemical properties, adjustable porosity, and the presence of electrocatalytically active sites for reactions, enabling its large-scale utilization in commercialized supercapacitors.

CHAPTER 2

OBJECTIVES

The aim of this study is to fabricate hybrid capacitors using a novel configuration and implement prototypes in a laboratory setting to investigate the effects of this novel configuration compared to conventional two-electrode systems. While extensive research has focused on the materials used for hybrid capacitor fabrication, limited attention has been given to the configuration of electrodes, despite its critical role in further development. The Prototypes were created using a straightforward mixture and loading technique for electrode materials. Polyethylene sheets were employed as separators to prevent short circuits between the electrodes and the aqueous Potassium Sulphate electrolyte solution. The charging-discharging cycle analysis was performed to determine the parameters of hybrid capacitors, including energy density, power density, internal resistance, and specific capacitance, for both the developed prototypes and conventional two-electrode hybrid capacitor prototypes.

A comparative analysis of various parameters for the developed prototypes was conducted, and readings were recorded. Charge-discharge tests revealed that the novel electrode configuration resulted in improved energy density, power density, and specific capacitance compared to conventional hybrid capacitors. Graphical analysis of charge-discharge data demonstrated a reduction in internal resistance.

Hybrid capacitors offer higher energy density and better long-term cycling ability compared to supercapacitors, making them attractive for applications that require repeated high current pulses. This technology is still under development with the potential to replace or complement batteries in the near future.

CHAPTER 3

LITERATURE SURVEY

[1] Activated Carbon/MnO2 Composites as Electrode for High Performance Supercapacitors. Jang Rak Choi 1,2, JiWon Lee 1, Guijun Yang 1, Young-Jung Heo 1 and Soo-Jin Park 1,*

This research paper gives idea about the activated Carbon/MnO2 composites as electrode for high performance supercapacitors. It also gives the general idea about the energy storage devices such as supercapacitor for which is mainly consists of positive electrode of MnO2/Carbon electrode composites.

In summary, AM composites with various mass ratios of MO were synthesized by the facile hydrothermal method. The AM composite electrodes exhibited higher specific capacitance than pure AC or MO electrodes. The effect of MnO2 on the electrochemical performance was evaluated by varying the AC:MO ratio. In a certain range, the addition of MnO2 improved the electrochemical performance of activated carbon, but with the increase of MnO2 addition, the excess porosity of MnO2 will cause a decrease of porosity, which will cause a decrease of the electrochemical performance of AM composites. The optimal ratio of AM composite is an AC:MO ratio of 1:1 (weight ratio). The electrochemical performance data indicated that the AM composites exhibit a good specific capacitance (60.3 F g−1) and rate performance. Furthermore, the AM composite electrodes exhibited significantly improved cycling stability.

[2] Long-term cycling behavior of asymmetric activated carbon/MnO2 aqueous electrochemical supercapacitor Thierry Brousse a,∗, Pierre-Louis Taberna b, Olivier Crosnier a, Romain Dugas a, Philippe Guillemet a, Yves Scudeller a, Yingke Zhoud, Fr´ed´eric Favier d, Daniel B´elanger c, Patrice Simonb.

This research paper discusses the electrochemical behaviour of hybrid capacitor and Long-term cycling behavior of asymmetric activated carbon/MnO2 aqueous electrochemical supercapacitor. This research paper also discusses the electrochemical behaviour of hybrid capacitor.

Activated carbon–MnO2 hybrid electrochemical supercapacitor cells have been assembled and characterized in K2SO4 aqueous media. A laboratory cell achieved 195,000 cycles with stable performance. The maximal cell voltage was 2 V associated with 21 ± 2Fg−1 of total composite electrode materials (including activated carbon and MnO2, binder and conductive additive) and an equivalent serie resistance (ESR) below 1.3 -cm2. Long-life cycling was achieved by removing dissolved oxygen from the electrolyte, which limits the corrosion of current collectors. Scaling up has been realized by assembling several electrodes in parallel to build a prismatic cell. A stable capacity of 380 F and a cell voltage of 2 V were maintained over 600 cycles. These encouraging results show the interest of developing such devices, including non-toxic and safer components as compared to the current organic-based devices. This study highlights the opportunity to develop large cells using these design and fabrication approaches, with non-toxic and safer components compared to the usual organic-based devices.

[3] Nanostructured Manganese Dioxide for Hybrid Supercapacitor Electrodes Jon Rodriguez-Romero, Idoia Ruiz de Larramendi * and Eider Goikolea *

This research paper specifies the specification of emerging energy storage device i.e. supercapacitor due to use of MnO_2 as the positive electrode and gives idea about the Nanostructured Manganese Dioxide for Hybrid Supercapacitor Electrodes.

Hybrid supercapacitors, as emerging energy storage devices, have gained much attention in recent years due to their high energy density, fast charge/discharge and long cyclabilities. Among the wide range of systems covered by this topic, low cost, environmental friendliness and high power provide MnO_2 with great characteristics to be a competitive candidate. The present work reports a hybrid aqueous supercapacitor system using a commercial activated carbon as the negative electrode and a synthesized manganese dioxide as the positive electrode. Two manganese dioxide polymorphs (α-MnO_2 and δ-MnO_2) were tested in different neutral and basic aqueous electrolytes. In this way, full cell systems that reached an energy density of 15.6 Wh kg^{-1} at a power density of 1 kW kg^{-1} were achieved. The electrode–electrolyte combination explored in this study exhibits excellent performance without losing capacity after 5000 charge/discharge cycles, leading to a promising approach towards more sustainable, high-performance energy storage systems.

[4] MnO_2/Carbon Composites for Supercapacitor: Synthesis and Electrochemical Performance Dan Wu1, Xiubo Xie1, Yuping Zhang1, Dongmei Zhang2, Wei Du1*, Xiaoyu Zhang1* and Bing Wang3

This research paper summarises the research in electrochemical performance of MnO_2/Carbon composites for supercapacitor in the recent years and tells about the MnO_2/Carbon Composites for Supercapacitor: Synthesis and Electrochemical Performance.

The literature review conducted gave a detailed view on the relevant state of art. An attempt was made to understand the materials used to manufacture supercapacitors and their influence on the electrical parameters of the supercapacitor. As per the review, the use of activated carbon to produce supercapacitors from plant species abundant in India was done to some extent by Khairnar and colleagues[49]. However, the work done by them only concentrated on activation by pyrolysis.

There was a need to find effective methods of activation for biomass indigenous to the subcontinent so that the resulting carbon would be better suited for supercapacitor electrodes. To enable widescale adoption of the supercapacitor as an efficient energy storage device, it was necessary to reduce the overall cost and size of the system. Another issue needed to make the device competitive was to make it environment friendly.

The use of statistical methods for design of experiments was studied and various methods of process optimization was reviewed. Though process modeling of the supercapacitor [29] have been attempted, it does not take into consideration the activation of the precursor. Optimizing both specific capacitance and the equivalent series resistance of a supercapacitor simultaneously has never been attempted. This type of multi-objective optimization required a new approach when the process model used was nonlinear in nature. There was a need to explore the research gaps discussed above and the current

work tries to address this. The relationship between the stored charge Q, the applied voltage V and the capacitance C is given by,

$C = Q/V$

In a capacitor, C is directly proportional to the surface area, A, of each electrode and inversely proportional to the distance d between them.

CHAPTER 4

METHODOLOGY

1. **Selection of Software** :

Different software like COMSOL Multiphysics, Fusion 360, Ansys, MATLAB were tested and out of which COMSOL Multiphysics have all required physics interphases and hence COMSOL is selected for simulation.

COMSOL software has all physics interfaces required for simulation of supercapacitor. It also has two types of study interface required for simulation. It is combination of CAD and simulation software.

2. **Geometry :**

In COMSOL software 3D geometry was created which replicate the overall structure of the supercapacitor. It has three layers which are sandwiched such that polyethylene separator and MNO2 + activated carbon at top which forms positive electrode and activated carbon electrode at bottom which forms negative electrode.
Dimensions of the each layer is 3 cm x 1 cm x 0.01 cm. They are sandwiched in such a way as three notebooks kept on one another.

3. **Selection of materials :**

There are different materials which can be used for designing of supercapacitor. But biomass materials are used to make supercapacitor environment friendly. Polyethylene is available in software and even electrode materials not available but it can be created in software by adding properties.

4. **Selection of physics interphase ;**

There are different physics interphases available in COMSOL out of which we have selected electrostatics and electrical circuits. Electrostatics is used to find capacitance of supercapacitor. Electrical circuits is used to plot charging and discharging graphs.

5. **Selection of study :**

Stationary and time dependent study are selected to analysis the supercapacitor. Stationary study is used to find capacitance of supercapacitor as capacitance independent of time. Time dependent study is used to plot charging and discharging graphs. Stationary study is compiled with electrostatics and time dependent study compiles with electrical circuits for simulation

CHAPTER 5

SOFTWARE ARCHITECTURE

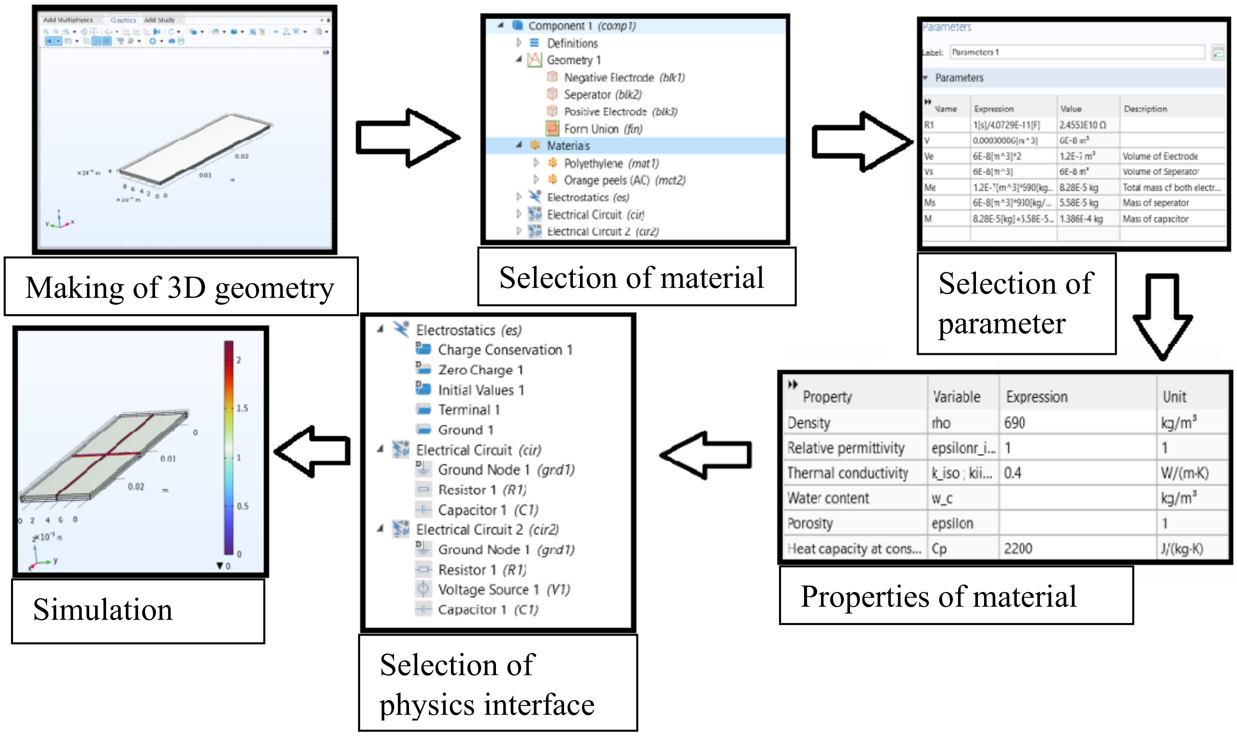

Fig. 5.1 – Software architecture

1. **Material selection and property:**

There are different materials which can be used for designing of supercapacitor. But biomass materials are used to make supercapacitor environment friendly. Polyethylene is available in software and even electrode materials not available but it can be created in software by adding properties.

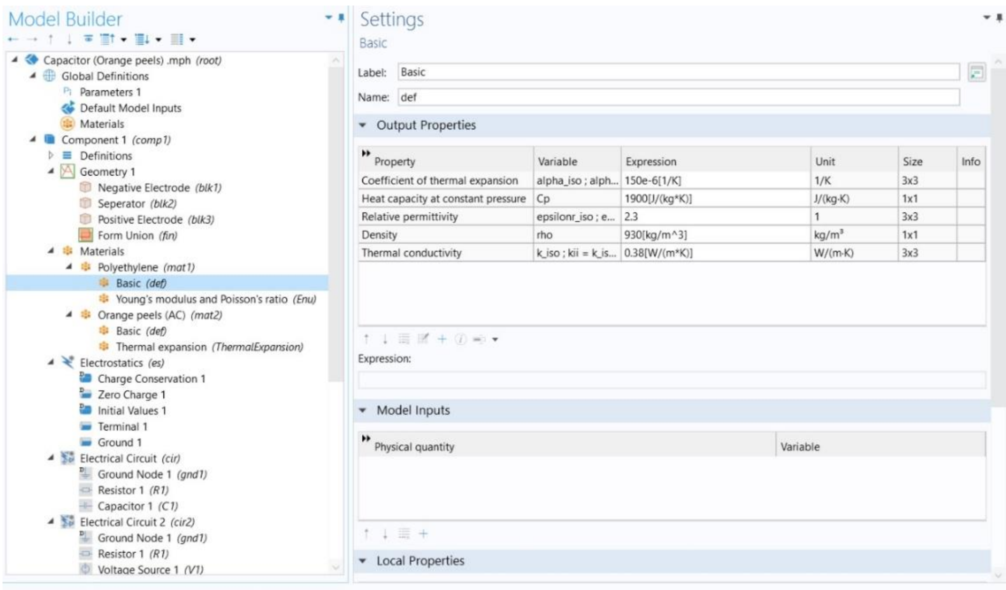

fig 5.2 – Material selection and property

2. Physics Interface:

There are different physics interphases available in COMSOL out of which we have selected electrostatics and electrical circuits. Electrostatics is used to find capacitance of supercapacitor. Electrical circuits is used to plot charging and discharging graphs.

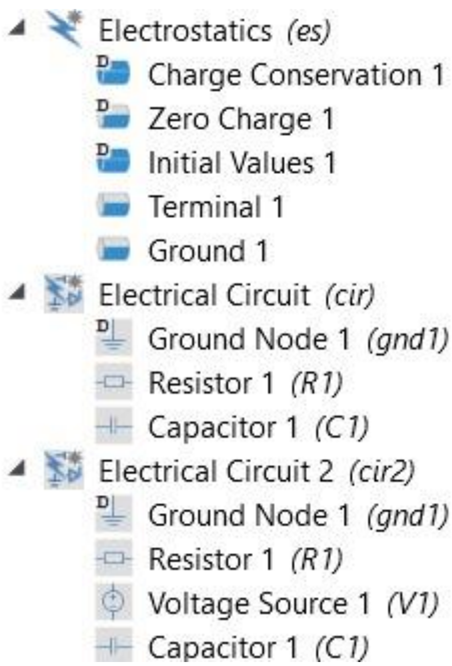

Fig. 5.3 – Physics interface

3. Time independent study:

Stationary and time dependent study are selected to analysis the supercapacitor. Stationary study is used to find capacitance of supercapacitor as capacitance independent of time. Stationary study is compiled with electrostatics for simulation.

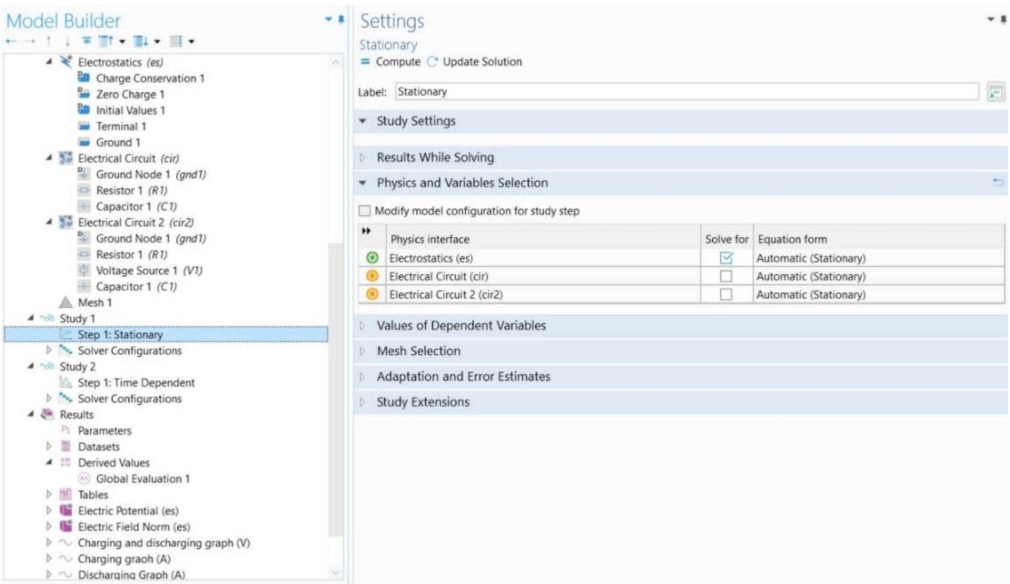

Fig. 5.4 – Time dependent study

4. Time dependent study

Stationary and time dependent study are selected to analysis the supercapacitor. Time dependent study is used to plot charging and discharging graphs. Time dependent study compiles with electrical circuits for simulation.

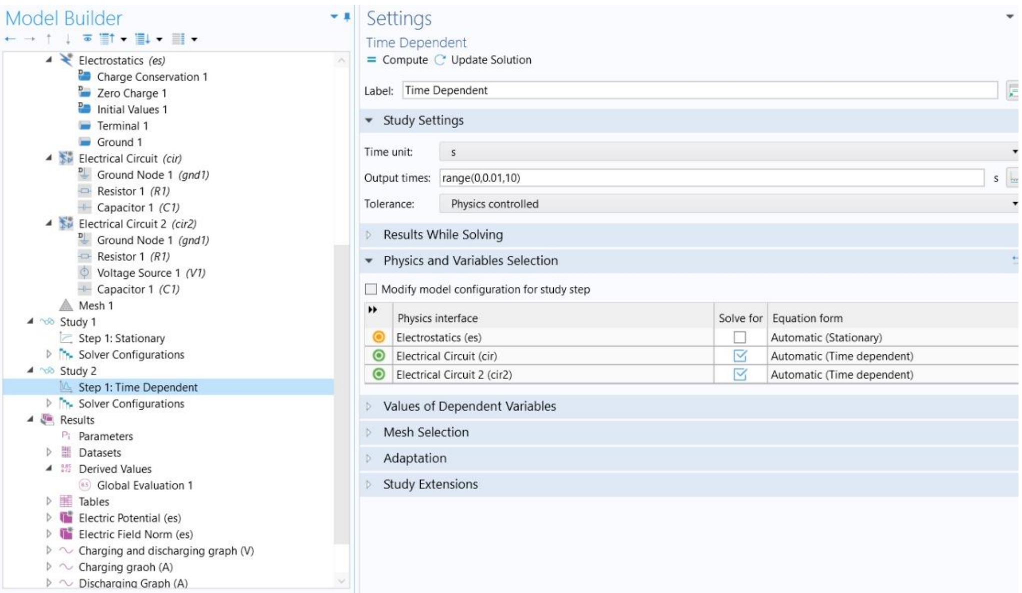

Fig. 5.5 – Time dependent study

5. Parameters:

COMSOL Multiphysics consist of most of formulae for calculation but not all. Hence some of the formulas should be included manually. Software consists the parameters section for manually adding formula which is used for calculation of volume, mass and resistance of supercapacitor.

Settings

Parameters

Label: Parameters 1

Parameters

Name	Expression	Value	Description
R1	1[s]/4.0729E-11[F]	2.4553E10 Ω	
V	0.00000006[m^3]	6E-8 m^3	
Ve	6E-8[m^3]*2	1.2E-7 m^3	Volume of Electrode
Vs	6E-8[m^3]	6E-8 m^3	Volume of Seperator
Me	1.2E-7[m^3]*690[kg/m^3]	8.28E-5 kg	Total mass of both electr...
Ms	6E-8[m^3]*930[kg/m^3]	5.58E-5 kg	Mass of seperator
M	8.28E-5[kg]+5.58E-5[kg]	1.386E-4 kg	Mass of capacitor

Fig. 5.6 – Parameter

6. Global evaluation:

COMSOL Multiphysics consists of a section named Global Evaluation which is used to calculate capacitance of supercapacitor. Formula for calculation capacitance is inbuilt while for calculating the specific capacitance formula should be added manually which is demonstrated in following figure.

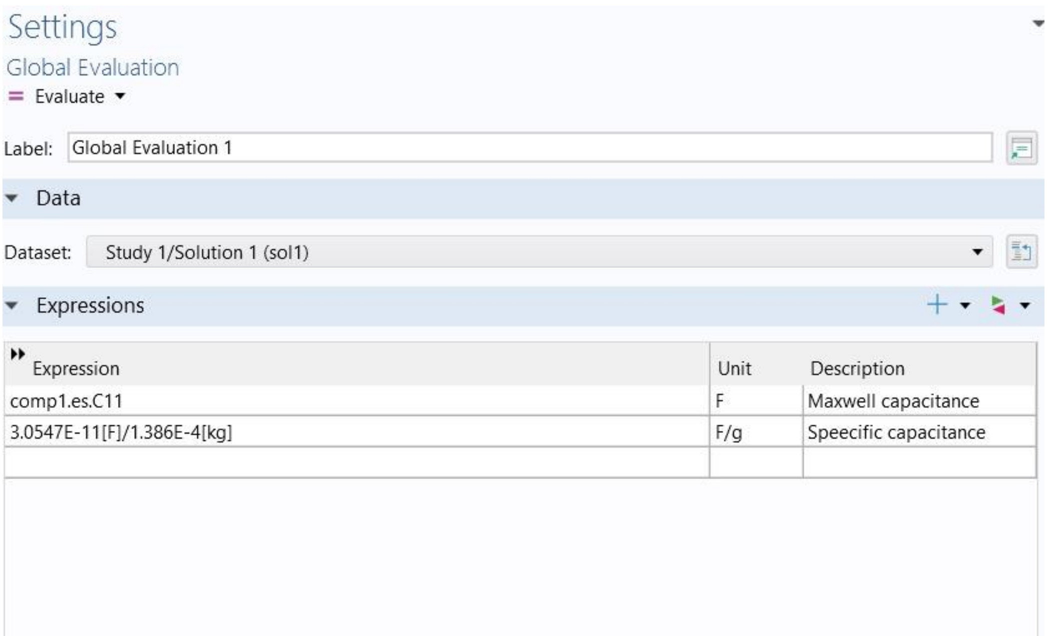

fig. 5.7 – Global evaluation

7. Charging & discharging graph:

Global evaluation section is used to plot charging and discharging graph. Global evaluation is compiled with electrical circuits interphase and time dependent study to plot the charging and discharging graphs. The graphs are exponential in nature which can be observed in following figure. The graph demonstrate an ideal version of supercapacitor which can be different while plotting the graph of hardware version of the supercapacitor as there is difference if practical and ideal version of supercapacitor.

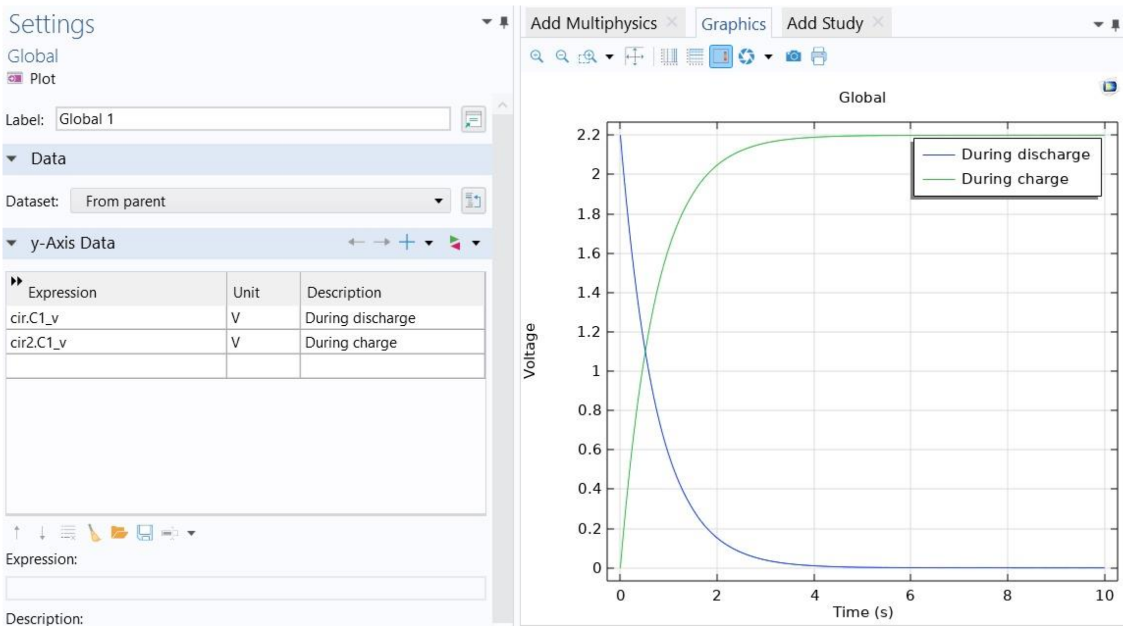

Fig. 5.8. – Charging and discharging graph

8. Charging – discharging graph and capacitance:

In following figure the graph shown are exponential in nature which are of ideal supercapacitor. The graphs are exponential in nature which can be observed in following figure. The graph demonstrate an ideal version of supercapacitor which can be different while plotting the graph of hardware version of the supercapacitor as there is difference if practical and ideal version of supercapacitor.

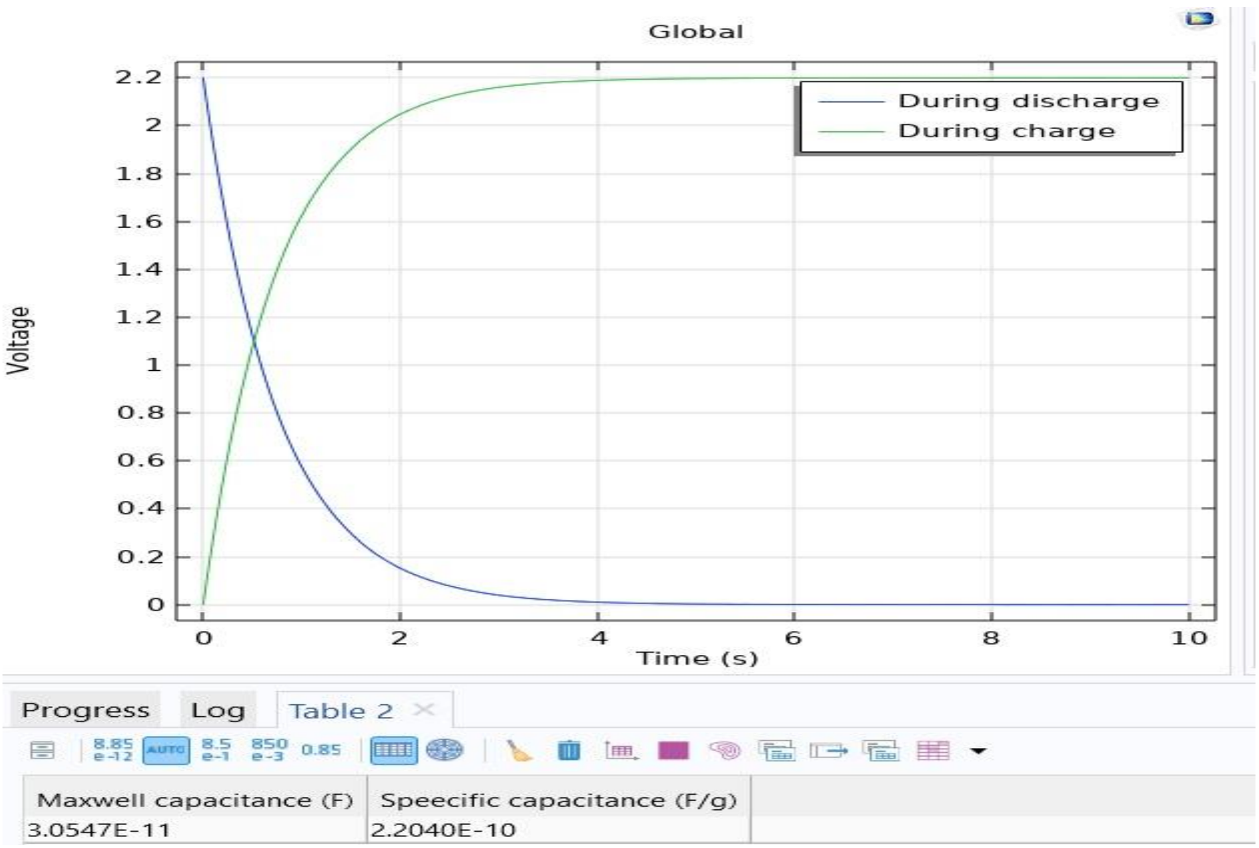

fig. 5.9 – Charging, discharging graph and capacitance

CHAPTER 6

HARDWARE PROCESS

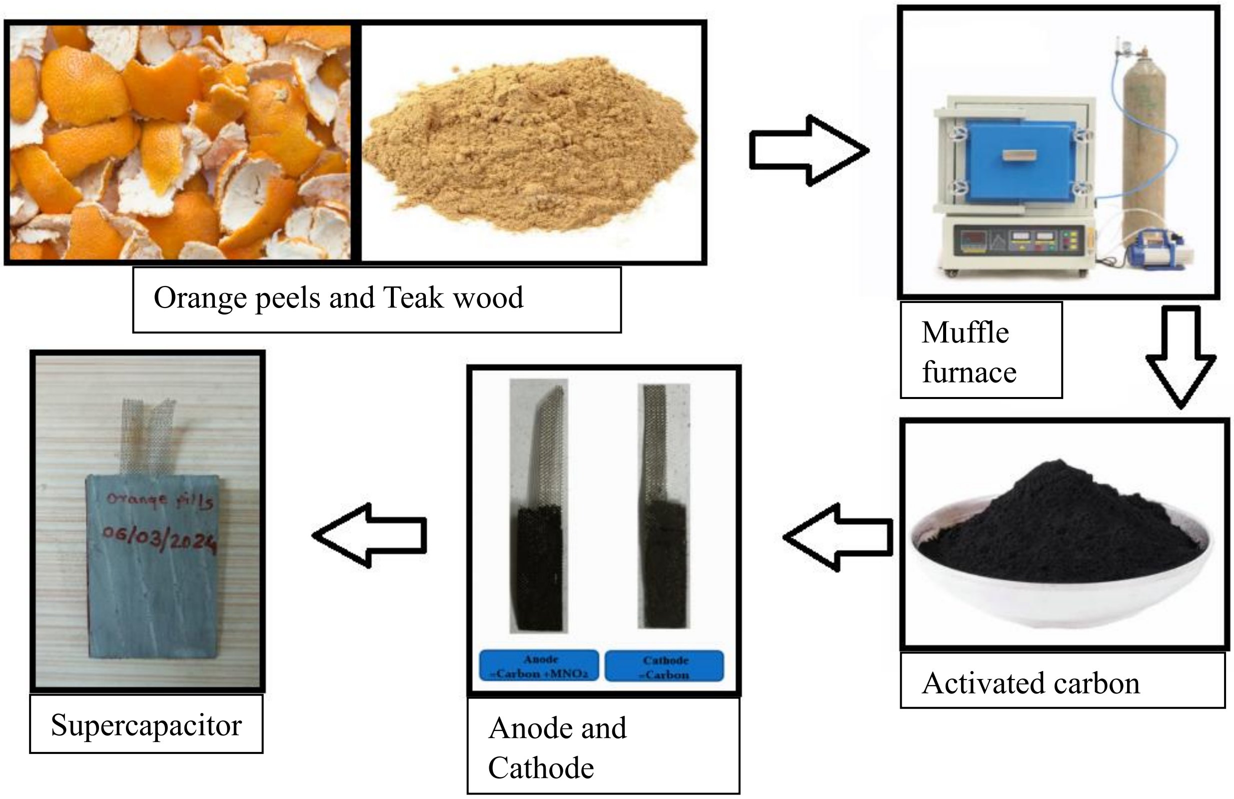

Fig 6.1 - Hardware process

1. **Material selection :**

   The materials have been selected for this process which are made up of biomass materials. First material is orange peels and another one is teak wood .

   There are many biomass materials are available like tamarind seeds , coconut husk , bagasse and many more but among these the orange peels and teak wood are easily available and easy to made carbon of these materials.

2. Properties of materials :

The materials which are selected are easily available, cheaper in cost, biodegradable, environment friendly and the detail properties are as mentioned in the table.

Due to these properties these materials are very effective to use in supercapacitor. properties plays very important role in the making of supercapacitor from this biomass materials.

	Orange peels	**Teak wood**
Density	**0.58 - 0.814 g/cm^3**	**0.6 - 0.7 g/cm^3**
Thermal conductivity	**0.3 - 0.5 W/M.K**	**0.12 - 0.20 W/M.K**
Moisture content	**80 - 88 %**	**10 – 14 %**
Pore size	**51.6 um - 56.4 um**	**10 um - 50 um**
Surface area	**40.84 - 45.42 m^2g**	**1-10 m^2g**
Specific Heat capacity	**2 - 2.24 J/g-k**	**0.58 J/g-k**
Value heat transfer	**-**	**4500 - 4800 kcal/kg**
Thermal Expansion coefficient	**6 - 9 u/m-k**	**10-50 u/m-k**
Ash content	**3 - 4 %**	**0.5 - 2 %**

Table no. 6.1 – Properties of materials

3. **Making of hardware :**

Shape and constructional details of supercapacitor :

In the construction of supercapacitor required materials are polyethylene sheets as a separator and a mesh sheet on which carbon has to be placed.

The anode and cathode of supercapacitor has been made up of mesh sheet for this the lower portion width is selected as 1 CM and length is 3 CM. For upper part 0.5 CM width and 3 CM length.

Just for not looking the same both anode and cathode ,the mesh sheet for anode is slightly cut at the top just to identify anode and cathode mesh sheet.

In making of supercapacitor the anode and cathode are superimpose on each other.

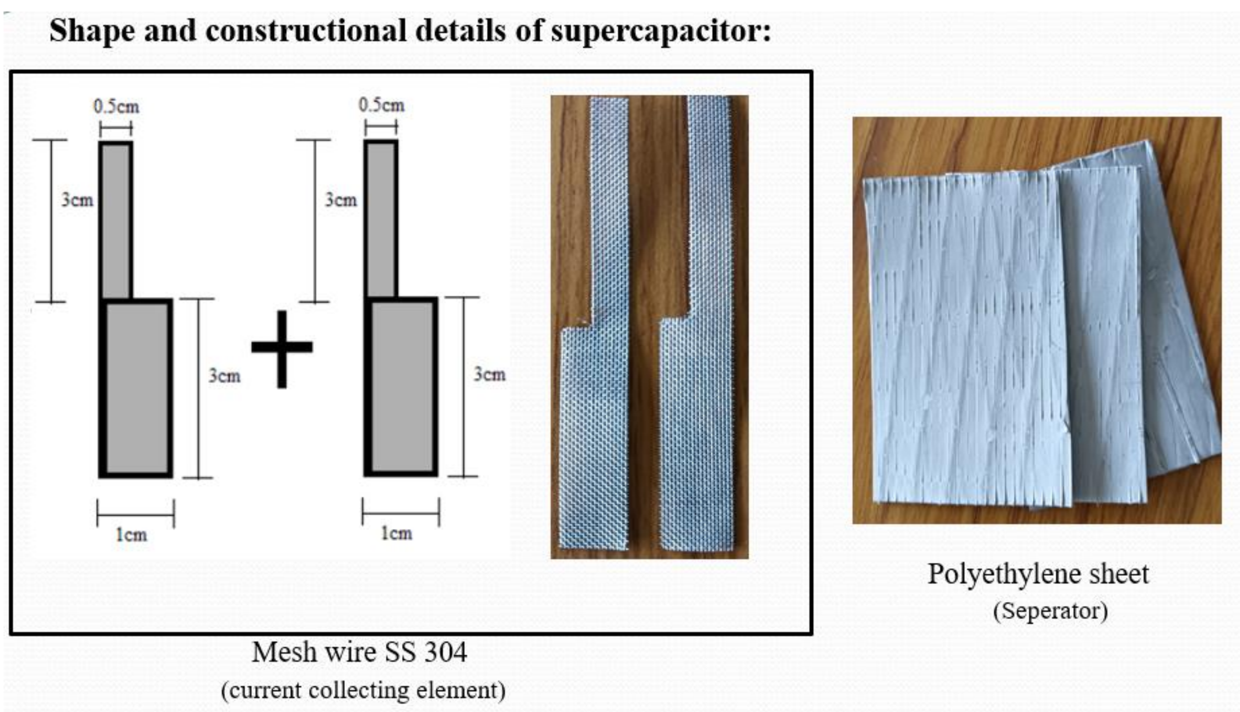

fig. 6.2 – Shape and constructional details of supercapacitor

4. Hardware process :

For hardware, on anode mesh sheet mixture of activated carbon and MNO2 is placed. On cathode mesh sheet only activated carbon is placed.

As per the circuit diagram the connections have been made after that the material of orange peels and teak wood one by one placed in the solution of K2SO4 and distilled water.

The voltage has been set as 2.2 V. Firstly the materials has been charged for 3 min for 3 times simultaneously time to discharge has been noted. In the second part materials has been charged for 1 min for 5 times and at the 5^{th} time corresponding voltage current and time to discharge has been noted.

Based on these data the calculations are performed to find the capacitance of these materials.

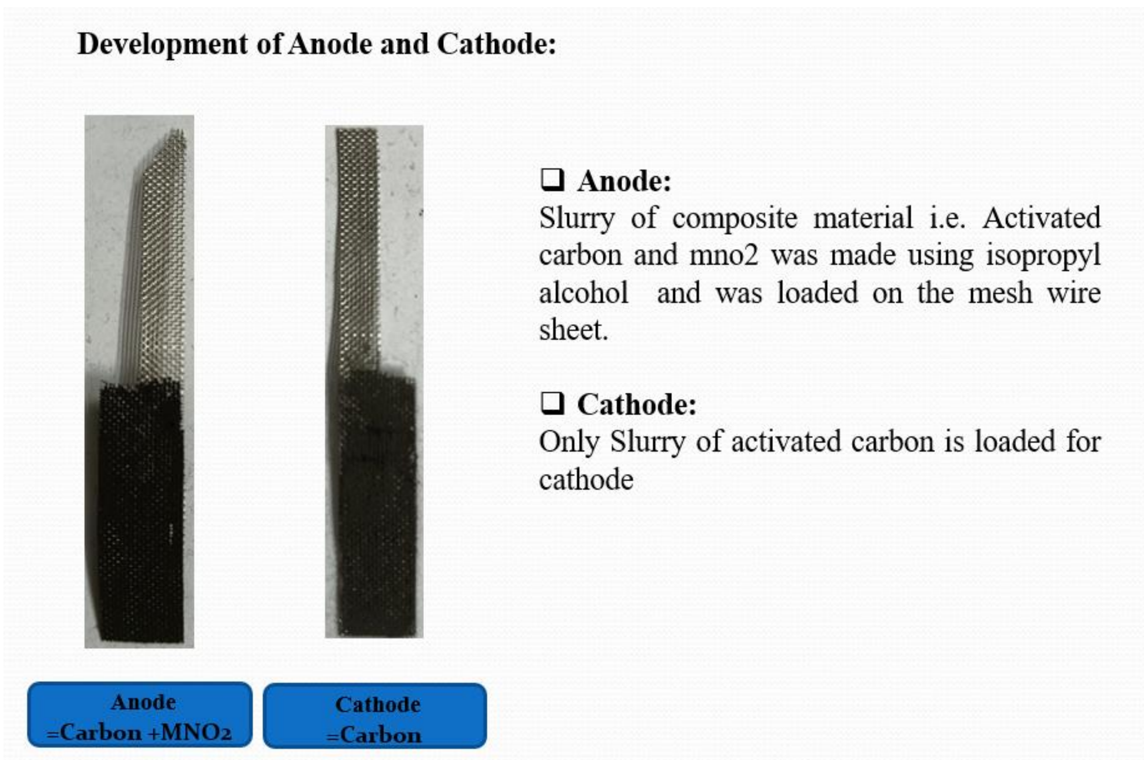

Fig. 6.3 – Development of anode and cathode

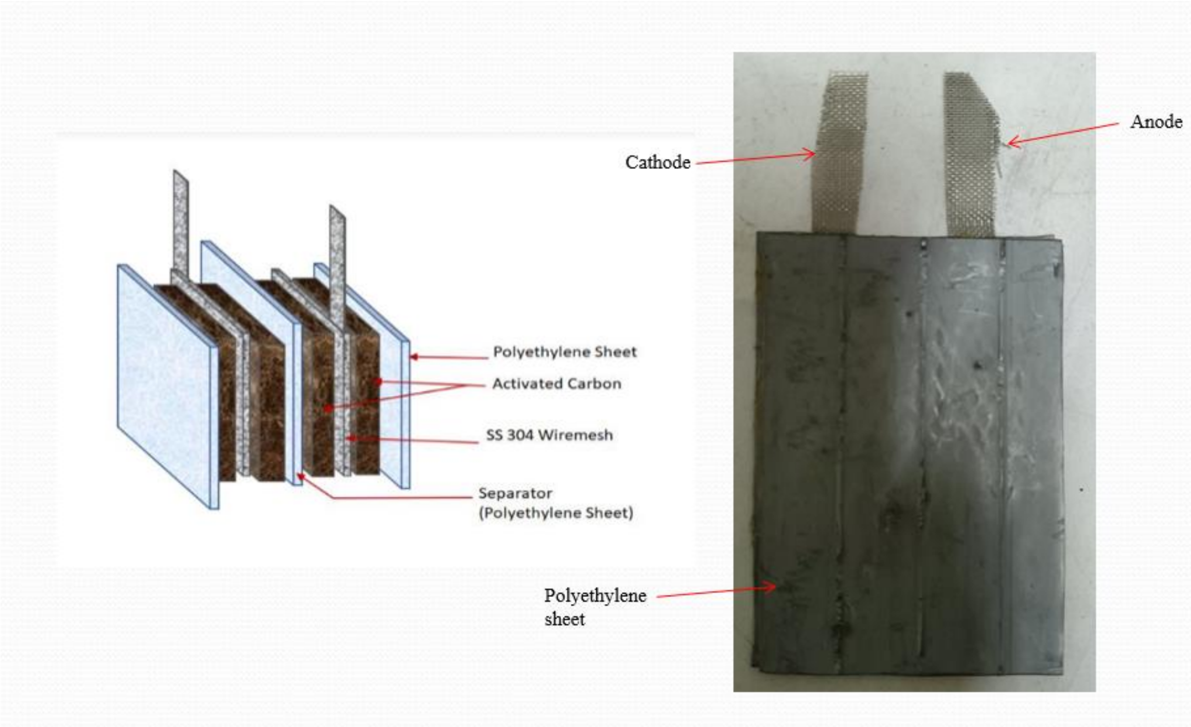

fig. 6.4 – Structure of supercapacitor

5. **Single cell of supercapacitor :**

Single cell of supercapacitor consist of three layers. one is anode layer. in the middle polyethylene is used as a separator and lastly cathode is placed.

Such a way single cell of supercapacitor has been made for testing. Following figure shows the single cells of supercapacitors of the orange peels and teak wood.

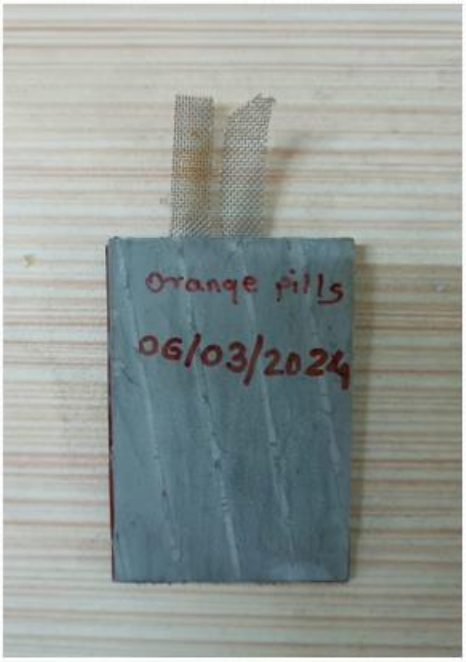

fig. 6.5 – Cell of supercapacitor

6. Testing of material :

- For testing of materials the connections have been made as per the circuit diagram.
- Single cell of supercapacitors like (orange peels/teak wood) material has been dipped in the solution of K2SO4 and distiled water.
- The voltage has been set to 2.2 V then the material has been charged for 3 min for 3 times and discharged time has been checked.
- Then charging for 1 min has been performed for 5 times and time to discharging has been checked.
- At 5^{th} time the time to discharge , corresponding voltage and current has been note down.
- With the help of these data calculations have been done.

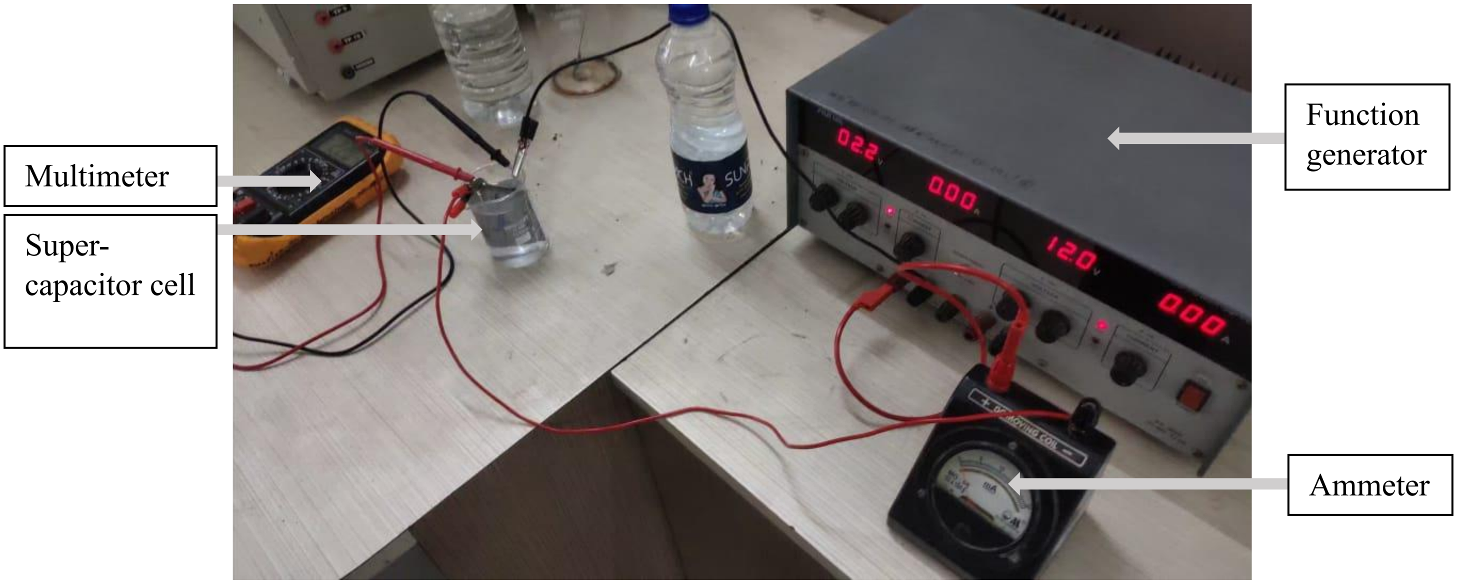

Fig. 6.6- Hardware testing process

CHAPTER 7

CALCULATIONS

Orange peals

Voltage	Time	Current
0.31	1	2.5
0.17	5	1.25
0.13	10	1.2
0.10	15	1.15
0.09	20	1.1
0.08	25	1.05
0.07	30	1
0.06	35	0.95
0.05	45	0.90
0.04	50	0.85
0.03	60	0.80
0.02	80	0.75
0.01	100	0.70

Table no. 7.1 – Readings of orange peel supercapacitor

Formula , $C = Q/V$

$Q = I1+I2 / 2\ t1 + I2 + I3 / 2\ t2 + I3 + I4 / 2\ t3 + \ldots\ldots\ldots\ldots$

$Q = 1.875 + 6.125 + 11.75 + 16.875 + 21.5 + 25.625 + 29.25 + 32.375 + 39.375 + 41.25 +$
$46.5 + 53$

$Q = 330.5$ C

$C = 330 / 2.2$

$= 150.22$

$$C = \frac{150.22}{0.12}$$

$C = 1251.83 \times 10^{-3}$ F/kg

$\boxed{C = 1.251 \text{ F/g}}$

Teak wood

Voltage	Time	Current
0.17	1	5
0.15	5	2.5
0.12	10	2
0.11	20	1.9
0.10	25	1.8
0.08	35	1.7
0.07	40	1.6
0.06	50	1.5
0.04	100	1.4
0.03	150	1.3
0.02	200	1.2
0.01	210	1.1

Table no. 7.2 – Readings of teakwood supercapacitor

Formula , C = Q/V

Q = I1+I2 / 2 t1 + I2 + I3 / 2 t2 + I3 +I4/ 2 t3 + …………

Q =3.75 + 11.25 + 19.5 + 37 + 43.75 + 57.75 + 62 + 72.5 + 135 + 187.5 + 230

Q = 860 C

C = 860 / 2.2

= 390.90

$$C = \frac{390.90}{0.12}$$

C = 3257.5 $\times 10^{-3}$ F/kg

$$\boxed{C = 3.2575 \text{ F/g}}$$

CHAPTER 8

RESULT

Material	Software results (Based on electrostatic physics interface)	Hardware results
Orange peels	3.0547E-11 F/g	1.251 F/g
Teakwood	2.2830E-10 F/g	3.2575 F/g

Table no. 8.1 – Result table

CHAPTER 9

ADVANTAGES

1. Environmental Sustainability: Biomass materials are renewable and sustainable, reducing dependence on finite resources and minimizing environmental impact compared to traditional electrode materials.

2. High Surface Area: Biomass-derived materials often possess a high surface area, providing more active sites for electrochemical reactions and enhancing the overall capacitance of the supercapacitor.

3. Low Cost: Biomass materials are generally cost-effective and readily available, contributing to the affordability of supercapacitor production.

4. Biodegradability: Biomass-derived electrodes are often biodegradable, addressing concerns about the end-of-life disposal of electronic devices and promoting a more eco-friendly lifecycle.

5. Reduced Environmental Impact: The use of biomass materials may result in a lower environmental footprint compared to conventional materials, contributing to more sustainable energy storage solutions.

6. Improved Energy Density: Asymmetric supercapacitors benefit from the combination of different electrode materials, potentially leading to higher energy density and improved overall performance.

CHAPTER 10

APPLICATIONS

1. Electric Vehicles: Asymmetric supercapacitors with biomass materials may find application in electric vehicles, contributing to energy storage systems that are environmentally friendly and capable of rapid charge/discharge cycles.
2. Used to store energy generated form regenerative breaking because it have high cycle life and have high power density.
3. Energy Harvesting:-Supercapacitors can be paired with energy harvesting devices, such as solar panels or vibration generators, to store energy efficiently for low-power applications like wireless sensors, remote monitoring systems, and IoT devices. They provide quick bursts of energy when needed.
4. Public Transportation:-Supercapacitors are used in Electric vehicle to provide rapid burst of energy for acceleration that help reduce energy consumption, extend battery life, and improve overall efficiency in urban transportation systems.
5. Supercapacitor used in power sources for laptops and flash in cameras.
6. Emergency Backup Systems: Biomass-derived asymmetric supercapacitors can serve as efficient energy storage solutions for emergency backup systems, providing reliable power during outages or in remote areas.

CHAPTER 11

CONCLUSION

Simulation of supercapacitor made of 2 different materials (Orange peels, Teak wood) have been tested and have found the specific capacitance of the materials and also the charging and discharging graph of the four materials have been found.

The current study concludes the hardware and software process of designing, simulation and testing process of the supercapacitor. The current study was able to identify the Teak wood crush and orange peels as a suitable precursor for activated carbon to be used as a supercapacitor's electrodes. The main conclusion from this study is that the material used as the electrodes of the supercapacitor are made up from the biomass materials.

Due to use of this materials, E-waste generated is less, the material is easily available as well as easily decompose. Hence it is much more environment friendly than any other electronic materials. The size of the supercapacitor is equivalent to the normal supercapacitor as well as the cost is also less.

CHAPTER 12

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