PES's MODERN COLLEGE OF ENGINEERING

Shivajinagar, Pune-5

DEPARTMENT OF ELECTRICAL ENGINEERING

CERTIFICATE

This is to certify that the project entitled:

"STUDY AND ANALYSIS OF SHAPE OF ELECTRODE IMPLEMENTED IN SUPER CAPACITOR WITH FOCUS ON DESIGN AND FABRICATION FOR APPLICATION IN LOAD"

Has been carried out successfully by

STUDENTS NAME	EXAM SEAT NO.
SANKET MAHAJAN	B190312587
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VAISHNAVI CHIRMADE	B190312525
SOHAN DALVI	B190312527

It is Bonfide work carried out by them under supervision of Prof. Mrs. M. P. Bhajekar 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.

Date: 1/6/23

Prof. Dr. (Mrs.) N. R. Kulkarni	02/06/23 **Signature of External Examiner**	**Prof. (Mrs.) M. P. Bhajekar**
(Head of Electrical Department)		**(Project Guide)**

A
PROJECT
REPORT ON

"STUDY AND ANALYSIS OF SHAPE OF ELECTRODE IMPLEMENTED IN SUPER CAPACITOR WITH FOCUS ON DESIGN AND FABRICATION FOR APPLICATION IN LOAD"

SUBMITTED IN PARTIAL FULFILLMENT OF THE

REQUIREMENT FOR THE DEGREE OF

BACHELOR OF ELECTRICAL ENGINEERING

SAVITRIBAI PHULE PUNE UNIVERSITY

BY

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DEPARTMENT OF ELECTRICAL ENGINEERING

PES's MODERN COLLEGE OF ENGINEERING,

PUNE -05

Year 2022-23

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(Project Guide)

ABSTRACT

This project report presents a comprehensive study and analysis of the electrode shape implemented in supercapacitors, with a specific focus on designing and fabricating electrodes for load applications. Supercapacitors are advanced energy storage devices known for their high-power density, rapid charge/discharge capabilities, and long cycle life. The shape of the electrodes has a significant impact on the performance of supercapacitors, particularly when applied to load scenarios. The objective of this project is to investigate various electrode shapes, assess their effects on supercapacitor performance, and develop optimized electrode designs for load applications. The project begins with an introduction to supercapacitors and the importance of electrode shape in their performance. A comprehensive literature review is conducted to understand the existing research and publications related to electrode shape in supercapacitors, identifying gaps and areas for further exploration.

Design considerations are then discussed, taking into account the specific requirements and characteristics of load applications. The selection of electrode materials based on their electrochemical properties and compatibility with load scenarios is explored. Various electrode shape options are evaluated, considering their potential advantages and limitations. Various electrode forms have been attempted and evaluated in these projects, with one shape being determined to be the optimal shape for supercapacitor electrodes.

ACKNOWLEDGMENT

As we are in our final semester of BE Electrical Engineering, we are aware that without the guidance of our bevelled professors, it would not have been possible to complete and present this project. It gives us immense pleasure in having an opportunity to express a deep sense of gratitude to our Principal, **Dr. Mrs. K.R. Joshi**, for providing us with necessary facilities. We are also very thankful to our Head of Department, **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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INDEX

LIST OF FIGURE

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

Supercapacitors, also known as Ultracapacitors or electrochemical capacitors, are energy storage devices that bridge the gap between traditional capacitors and batteries. They have gained significant attention in recent years due to their unique characteristics and potential applications. Supercapacitors offer high-power density, fast charge/discharge capabilities, and long cycle life, making them ideal for applications that require quick bursts of energy or frequent cycling. The significance of supercapacitors in energy storage arises from their ability to store and deliver large amounts of energy in a short period. Unlike batteries, which store energy through chemical reactions, supercapacitors store energy through the physical separation of charge on the electrode-electrolyte interface. This mechanism allows for rapid charge and discharge cycles, enabling supercapacitors to deliver high power when needed.

In the context of supercapacitors, the shape of the electrodes plays a crucial role in determining the overall performance of the device. The electrode shape affects various aspects, including the available surface area for charge storage, ion diffusion pathways, and electrical conductivity. Different electrode shapes can lead to variations in capacitance, energy density, power density, and cycling stability. Therefore, optimizing the electrode shape is essential for enhancing the performance of supercapacitors. The objective of this project is to study and analyse the impact of electrode shape on supercapacitor performance, particularly in the context of load applications. Load applications refer to scenarios where supercapacitors are used to power devices or systems that require high-power output, such as electric vehicles, portable electronics, or renewable energy systems. By investigating various electrode shapes and their effects on performance, the project aims to develop optimized electrode designs that can maximize energy storage and deliver efficient power to loads.

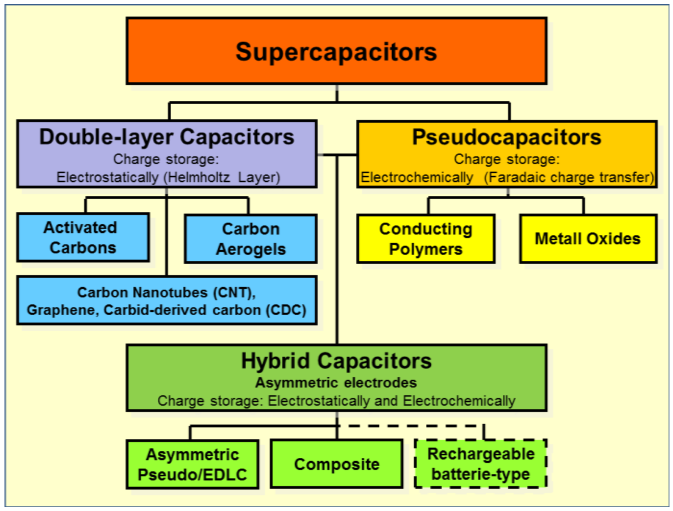


Fig 1.1 Types of Super capacitor

The key advantage of supercapacitors is their ability to store and release electrical energy rapidly. Unlike batteries, which store energy in chemical reactions and release it over a longer period, supercapacitors can charge and discharge within seconds or even milliseconds. This characteristic makes them ideal for applications that require high power bursts or rapid energy regeneration, such as electric vehicles, hybrid vehicles, regenerative braking systems, and energy harvesting systems. Supercapacitors also have an exceptional cycle life, meaning they can undergo a large number of charge-discharge cycles without significant degradation. This durability is due to the absence of chemical reactions during energy storage and retrieval. Moreover, supercapacitors can operate effectively across a wide temperature range, making them suitable for various environments and climates.

However, supercapacitors have limitations compared to batteries. They typically have lower energy densities, meaning they can store less total energy per unit mass or volume. As a result, supercapacitors are often used in conjunction with batteries, complementing their high power capabilities and improving overall system performance.

1.2 PROJECT MOTIVATION

- Enhanced Energy Storage
- Efficient Power Delivery
- Design Flexibility
- Manufacturing Optimization
- Environmental Sustainability

Super capacitors, also known as ultra-capacitors or electrochemical capacitors, are energy storage devices that can deliver high power density and long cycle life. By studying and analysing the shape of the electrodes, researchers aim to improve the energy storage capacity of supercapacitors. Optimizing the electrode shape can increase the surface area available for charge storage, leading to higher energy density and improved performance.

Supercapacitors are capable of delivering high power output, making them suitable for applications that require rapid energy release. By investigating electrode shapes, researchers can develop designs that maximize the power delivery capabilities of supercapacitors. This is particularly important for load applications where a high power demand is required, such as electric vehicles, hybrid energy systems, and heavy machinery.

The shape of the electrode plays a crucial role in determining the overall size, weight, and form factor of a supercapacitor. By studying different electrode shapes, researchers can explore innovative designs that offer improved integration and packaging options. This flexibility in design can enable the integration of supercapacitors into various load applications, even in space-constrained environments.

Investigating the fabrication techniques and processes associated with electrode shapes can lead to improvements in the manufacturing efficiency and cost-effectiveness of supercapacitors. By understanding the influence of electrode shape on the fabrication process, researchers can identify ways to streamline production, reduce material waste, and enhance overall manufacturing yield.

Supercapacitors are considered more environmentally friendly compared to traditional batteries due to their lower toxicity and longer lifespan. By focusing on the design and fabrication of electrodes for supercapacitors, researchers aim to contribute to the development of sustainable energy storage solutions.

1.3 BACKGROUND THEORY

The background theory of the project "Study and Analysis of Shape of Electrode Implemented in Supercapacitor with Focus on Design and Fabrication for Application in Load" revolves around the principles and concepts related to supercapacitors, electrode materials, and the impact of electrode shape on their performance. Here are some key background theories relevant to the project:

I. Supercapacitors:

Supercapacitors, also known as electrochemical capacitors or ultra-capacitors, are energy storage devices that store electrical energy through the separation of charges at the electrode-electrolyte interface. They differ from conventional capacitors by utilizing electrochemical processes, such as ion adsorption or redox reactions, to store and release energy.

Supercapacitors offer higher power density and faster charge/discharge rates compared to batteries, making them suitable for applications requiring rapid energy delivery.

II. Double Layer Capacitance:

The electrical energy storage mechanism in supercapacitors is primarily based on the concept of double layer capacitance. When a voltage is applied across the electrodes in an electrolyte solution, ions from the electrolyte form layers of charges (double layer) on the surface of the electrodes.

The separation of charges at the electrode-electrolyte interface creates an electrical double layer, resulting in the storage of electrical energy.

III. Electrode Materials:

Electrode materials play a crucial role in the performance of supercapacitors. They provide a high surface area for ion adsorption and desorption. Common electrode materials include activated carbon, carbon nanotubes, conducting polymers, metal oxides, and composites.

Each material has specific properties that affect the capacitance, energy density, and cycling stability of the supercapacitor.

IV. Electrode Shape:

The shape of the electrode influences the surface area, ion diffusion, and charge transport within the supercapacitor. Different electrode shapes, such as rectangular, square, semi-circular, or triangular, can impact the overall performance and efficiency of the supercapacitor. Electrodes with larger surface areas provide more active sites for ion adsorption, leading to higher capacitance.

Electrode shape also affects the distance that ions need to travel, influencing the charge and discharge rates.

COMPARISON OF VARIOUS TYPES OF SUPER CAPACITORS:

PARAMETERS	SUPER CAPACITOR	HYBRID SUPER CAPACITOR	ASYMMETRICAL SUPER CAPACITOR	HYBRID BATTERY
Definitions	A super capacitor is a type of capacitor that can store a large amount of energy, typically 10 to 100 times more energy per unit mass or volume compared to electrolytic capacitors. https://www.techopedia.com/definition/30407/super capacitor	Hybrid super capacitors are the devices with elevated capacitance and elevated energy storage capability. https://doi.org/10.1016/j.rser.	Asymmetrical super capacitor is a super capacitor based on two different electrode materials. One electrode is based on redox (Faradic) reactions with or without non-faradic reactions, and the other one is mostly based on electric double-layer (non-Faradic or electrostatic) absorption/desportion. https://doi.org	A hybrid car battery is like any other battery, aside from its ability to be recharged. https://www.thehybridgeek.com/
Cell Voltage	2.3 to 2.75 V https://batteryuniversity.com/	3.8 V https://www.powerelectronictips.com/	2.0 V https://agris.fao.org/	1.2 V https://www.caranddriver.com/
Operating Temperature	−40 to +70 °C https://www.electronics-cooling.com	-25 °C to +70 °C https://www.eaton.com/	Room Temperature to −20 °C https://pubs.rsc.org/	+24°C to +26°C https://www.dubizzle.com/

Charge Time	1 to 10 sec https://batteryuniversity.com/	Less than 5 min https://www.nature.com/	10 to 15 min https://www.sciencedirect.com/topics/chemistry/asymmetric-super capacitor	10 hours to half an hour https://www.energuide.be/en/
Discharge Time	100 to 50 percent in 30 to 40 days https://batteryuniversity.com/	Few min https://www.eaton.com/content/	Few Seconds https://www.researchgate.net/	5 % or less http://mit.edu/evt/summary_battery_specifications.pdf
Current Density	50 A/g https://doi.org/10.3390%2	0.25 A/g https://doi.org/10.1016/j.est.	1 mA/cm^2 https://pubs.rsc.org/en/content/	100 mA/cm^2 https://doi.org/10.1039/
Energy Density	9.58 Wh/kg https://doi.org/10.3390%2	28.8 Wh/kg https://doi.org/10.1016/j.est.	39.9 Wh/kg https://pubs.rsc.org/en/content/	12.8 mWh/cm^2 https://doi.org/10.1039/

.Table 1.1. Comparison of various types of super capacitors

1.4 OBJECTIVES

- To create the super capacitors of different shapes and of different materials.
- Obtaining highest capacitance using various shapes of Super capacitors.
- Increase Electrode Performance for Load Application
- Develop Supercapacitors with Different Electrode Shapes.
- Comparing and defining performance metrics.
- Deliver Knowledge for Future Fabrication

Investigate the Impact of Electrode Shape:

The project aims to study and analyse the effect of different electrode shapes, such as rectangular, square, semi-circular, and triangular, on the performance of supercapacitors. It seeks to understand how the shape influences specific capacitance, energy density, power density, charge/discharge rates, and overall efficiency.

Optimize Electrode Design for Load Application:

The project aims to identify the electrode shape that provides the best performance characteristics for applications in load-levelling. It aims to optimize the electrode design to enhance the energy storage capacity and power delivery capabilities of the supercapacitor specifically for load-based applications.

Fabricate Supercapacitors with Varying Electrode Shapes:

The project involves the fabrication of supercapacitors using different electrode shapes. It focuses on the design and fabrication processes, including material selection, deposition techniques, and shaping methods, to create supercapacitors with the desired electrode geometries.

Characterize and Compare Performance Metrics:

The project aims to characterize the performance of the fabricated supercapacitors with different electrode shapes. It includes evaluating specific capacitance, energy density, power density, charge/discharge rates, cycling stability, and other relevant metrics. The objective is to compare and analyse the performance of supercapacitors with different electrode shapes and identify the optimal shape for load applications.

Provide Insights for Future Design and Fabrication:

Through the study and analysis, the project aims to provide insights and recommendations for future design and fabrication of supercapacitors. It intends to contribute to the knowledge and understanding of the impact of electrode shape on supercapacitor performance, guiding future research and development efforts in the field.

1.5 PROJECT CONTRIBUTIONS

The project on the "Study and Analysis of Shape of Electrode Implemented in Supercapacitor with Focus on Design and Fabrication for Application in Load" makes several contributions to the field of supercapacitor technology and energy storage systems.

Enhanced Understanding of Electrode Shape Impact:

The project contributes to a better understanding of how electrode shape influences the performance of supercapacitors. By systematically studying and analysing different electrode shapes, the project provides insights into the relationship between shape and specific capacitance, energy density, power density, charge/discharge rates, and overall efficiency.

Optimization of Electrode Design for Load Applications:

The project aims to optimize the electrode design specifically for load applications. By focusing on electrode shape and its impact on supercapacitor performance, the project identifies the optimal electrode shape that provides the best energy storage capacity and power delivery capabilities for load-levelling and other load-based applications. This optimization contributes to the development of more efficient and effective energy storage solutions for meeting load demands.

Fabrication Techniques and Methods:

The project involves the fabrication of supercapacitors with different electrode shapes. Through the design and fabrication process, including material selection, deposition techniques, and shaping methods, the project contributes to the development of practical and scalable fabrication techniques for creating supercapacitors with specific electrode geometries. This knowledge can help researchers and engineers in effectively manufacturing supercapacitors with tailored electrode shapes.

Performance Evaluation and Comparison:

The project characterizes and compares the performance of supercapacitors with different electrode shapes. By evaluating specific capacitance, energy density, power density, charge/discharge rates, and cycling stability, the project provides valuable data and insights for comparing the performance of supercapacitors with various electrode shapes. This comparative analysis contributes to the understanding of the advantages and limitations of different electrode shapes in terms of their energy storage capabilities.

Recommendations for Future Research and Development:

Based on the findings and analysis, the project provides recommendations for future research and development in the field of supercapacitors. These recommendations may include further optimization of electrode shapes, exploration of advanced fabrication techniques, investigation of composite electrode materials, and integration of supercapacitors with other energy storage systems. These recommendations guide future efforts to enhance the performance and efficiency of supercapacitors for various applications.

1.6 ORGANIZATION OF PROJECT

Chapter 1: This chapter includes the introduction about supercapacitor’s, materials and its applications.

Chapter 2: This chapter includes the literature review about the shapes of supercapactior.

Chapter 3: This chapter includes the methodology of testing and designing of supercapacitor.

Chapter 4: This chapter includes the experimental setup of the testing of the supercapacitor.

Chapter 5: This chapter includes results and graphs of the experimental setup.

Chapter 6: This chapter includes the conclusion and future scope of the shapes of supercapacitor.

CHAPTER 2

LITERATURE SURVEY

Supercapacitors are divided into three types depending on their electrode configuration: symmetric supercapacitors, asymmetric supercapacitors, and battery-type supercapacitors. Symmetric supercapacitors have a pair of electrodes with identical behaviour on both sides of them. Supercapacitors (which are additionally referred to as Ultracapacitors) electrochemically store charge.

Supercapacitors are categorized into two categories based on charge storage: Electrochemical double layer capacitors (ELDCs) and Pseudocapacitors. Electrochemical Double Layer Capacitors (ELDCs) are charge storage devices with a high energy density. Carbon nanomaterials such as carbon nanotubes and graphene are used as electrodes in Electrochemical Double Layer Capacitors (ELDCs). Pseudocapacitors store energy by charge transfer between electrode and electrolyte [1].

The most prevalent kind of supercapacitor is the symmetric capacitor. Asymmetric supercapacitor design is simpler than symmetric supercapacitor design. Symmetric supercapacitors in aqueous electrolytes may achieve a high cell voltage while also improving energy density.

Manganese (Mn)-based materials are the most researched electrode materials based on metal oxides. Increasing the working potential of Mn_3O_4 enhances the energy of supercapacitors in aqueous electrolytes [2].

Electrochemical energy storage devices commonly referred as Flexible Symmetric Supercapacitors (FSS). The high density, expanded cycle life, and flexibility of Flexible Symmetric Supercapacitors (FSS) are well recognized. The layer of one solid electrode is coated by two electrode layers in Flexible Symmetric Supercapacitors (FSS). The development of nanomaterials is critical for improving the performance of Flexible Symmetric Supercapacitors (FSS). The needed solid electrolytes must be mechanically bendable [3].

Supercapacitor technology is advancing in order to deliver enhanced energy storage application platforms. Fabrication of supercapacitors is critical for speedy charging as well as improving qualitative performance.

Electrodes are typically made of metal oxides. Metal oxides are highly conductive. Concentrated MnO_2 and MnO_2 doped V_2O_5 with high capacitance density have been explored. The metal oxides explored for electrodes are both cost effective and environmentally favourable [4].

The asymmetrical supercapacitors operational voltage is maximized by employing two distinct materials on the electrodes. Graphene oxides are used to create asymmetric supercapacitors with high energy density. MnO_2 is placed on the positive electrode, while RGO is applied to the negative electrode before being immersed in Na_2SO_4 electrolyte. Asymmetric capacitor technology makes use of both the no faradic charge storage demonstrated by carbon materials and the nonfaradic charge storage demonstrated by pseudo capacitance. This capacitor architecture boosts capacitance and energy density while allowing for a high cycle life, combining the benefits of both electrostatic and faradic storage [5] [6].

Energy storage systems are in great demand due to the introduction of new electric vehicles that employ battery systems that require extended charging times of up to 7-8 hours and are expensive. The supercapacitor is utilised as an alternate method of energy storage since it charges quickly and provides a high supply of energy. A capacitor is a tool that stores energy in an electrostatic field and is utilised as needed. The supercapacitor is a double-layered, more energy-dense variant of the capacitor that was invented more recently. The area and capacitance both increase as a result of the second layer. Supercapacitors may be applied in a variety of forms and sizes and are more adaptable and simple to use than batteries [7][8][9].

Solid-state, thin, flexible, secure, and economically viable energy storage devices that can be easily integrated with printable and wearable electronics are imperative due to the rapid growth of these innovations in technology. These applications are particularly suited for solid supercapacitors (also known as electrochemical double layer capacitors, or EDLC), whose main components, solid polymer electrolytes and carbon electrodes, can both be produced entirely of ecologically friendly and sustainable materials. An affordable raw material for biomass (wood, agricultural waste, etc.) has been ignited to produce biochar activated carbons (AC), which are then further adjusted or modified by chemical activation. EDLC electrode materials showing potential. The primary characteristics of biochar AC for various energy storage applications are its extremely high surface area, micro- and meso-pore structures, and surface chemistries [10].

The need for more energy globally is driving the development of unconventional or alternative energy sources with high power and energy densities. Typical non-conventional energy sources based on the principle of chemical-to-electrical energy conversion include batteries, fuel cells, and supercapacitors. They have numerous uses in consumer electronics, including hybrid cars, digital cameras, emergency doors, and mobile phones. Electrochemical processes are used in these devices to transform chemical energy into electrical energy. As far as the fuel cells are concerned, electrical energy can be produced as long as the fuel is fed. With batteries, the energy that has been stored can be used when it is needed [11].

Concerns regarding climate change, the negative effects of petroleum dependence for many nations, and an increasingly interconnected world require significant improvements. Electrical energy storage systems (ESS) have grown to be a significant field of study as a result of the increase of renewable energy generation, electrification of the transportation sector, and increasing demand for wireless electrical devices. Traditional capacitors have optimal performance with cycle times in the order of ms or s (e.g. power converters) while Li-ion batteries are suitable for applications require charge-discharge cycles of a few hours (for example, PV self-consumption) [12].

CHAPTER 3

METHODOLOGY

3.1 BASIC DESIGN OF A SUPERCAPACITOR:

A supercapacitor, also known as an electrochemical capacitor or Ultracapacitors, is an energy storage device that operates based on the principles of electrostatic double-layer capacitance and pseudo capacitance.

ELECTRODES: Supercapacitors consist of two electrodes, namely the cathode and the anode. These electrodes are typically made of materials with high surface area and good electrical conductivity to facilitate charge storage and transfer. Common electrode materials include activated carbon, carbon nanotubes, metal oxides, and conductive polymers.

ELECTROLYTE: The electrolyte in a supercapacitor is responsible for facilitating the transport of ions between the electrodes. It serves as a medium for ion diffusion and charge transfer during the charge and discharge processes. The choice of electrolyte depends on the specific application requirements and desired performance characteristics. Common electrolytes used in supercapacitors include aqueous solutions such as sulphuric acid (H_2SO_4) or potassium hydroxide (KOH), as well as organic electrolytes and ionic liquids.

SEPARATOR: The separator is a porous membrane placed between the positive and negative electrodes to prevent direct electrical contact and short-circuiting. The separator allows for ion transport while blocking the passage of electrons. It is typically made of materials with high porosity, good ionic conductivity, and mechanical stability. Common separator materials include polymer membranes such as polyethylene (PE), polypropylene (PP), or ceramic materials like alumina (Al_2O_3) and zirconia (ZrO_2).

HOUSING: Supercapacitors are enclosed in a housing that provides mechanical support, electrical insulation, and protection against external environmental factors. The housing is typically made of a durable and chemically inert material such as plastic or metal. It ensures the integrity and safety of the supercapacitor assembly.

The basic design of a supercapacitor involves arranging the two electrodes with a separator in between and immersing them in the electrolyte. The electrodes are usually connected to external terminals that allow for the connection of the supercapacitor to an electrical circuit.

3.2 WORKING PRINCIPLE OF SUPERCAPACITOR:

The working principle of a supercapacitor is based on the electrostatic storage of charge at the electrode-electrolyte interface. Supercapacitors, also known as Ultracapacitors or electrochemical capacitors, can store and release electrical energy rapidly, making them suitable for high-power applications.

DOUBLE-LAYER CAPACITANCE:

When a voltage is applied to a supercapacitor, the (cathode) attracts negatively charged ions from the electrolyte, while the (anode) attracts positively charged ions. This results in the formation of an electrical double layer at the electrode-electrolyte interface. The double layer consists of a compact layer of ions adsorbed on the electrode surface, known as the Helmholtz layer, and a diffuse layer where ions are distributed in the electrolyte. The separation of charges at the electrode-electrolyte interface creates a potential difference and leads to the formation of an electrostatic field. The energy stored in this electrostatic field is known as double-layer capacitance. The double-layer capacitance primarily contributes to the energy storage in supercapacitors and is responsible for their high power density and rapid charge/discharge capability.

Supercapacitors offer several advantages over traditional capacitors and batteries, including high power density, long cycle life, fast charging/discharging rates, and wide operating temperature ranges. However, their energy density is generally lower than that of batteries. Supercapacitors are commonly used in applications that require rapid energy delivery, such as electric vehicles, renewable energy systems, regenerative braking, and power backup systems.

3.3 STORAGE PRINCIPLE OF SUPERCAPACITOR:

The storage principle of a supercapacitor is based on the electrostatic storage of electrical energy.

The primary storage mechanism in a supercapacitor is double-layer capacitance. When a voltage is applied across the electrodes, an electrochemical interface, known as the double layer, forms at the electrode-electrolyte interface. The double layer consists of two regions:

Helmholtz layer: This is a compact layer of ions adsorbed on the electrode surface. It forms due to the attraction between the charged electrode and counter ions from the electrolyte. The ions in this layer are strongly attached to the electrode surface.

Diffuse layer: This is a region where the ions are dispersed in the electrolyte, creating an ionic cloud around the electrode surface. The ions in the diffuse layer are not directly attached to the electrode but are still influenced by its charge.

The double layer acts as a dielectric, with the electrode acting as one plate and the electrolyte ions acting as the other plate. The separation of charges at the electrode-electrolyte interface results in the storage of electrical energy. The amount of charge stored in the double layer is proportional to the surface area of the electrodes and the electrolyte's ion concentration. Double-layer capacitance allows supercapacitors to deliver high power density and exhibit rapid charge and discharge capabilities.

3.4 VARIOUS SHAPES OF ELECTRODES FOR SUPER CAPACITOR

Electrode shape plays a crucial role in the performance of supercapacitors, influencing key parameters such as specific capacitance, power density, energy density, and charge/discharge efficiency. Here is a detailed description of various electrode shapes commonly used in supercapacitor research:

RECTANGULAR ELECTRODE: A rectangular electrode is one of the simplest and commonly used shapes in supercapacitors. It consists of a flat surface with straight edges. The advantages of rectangular electrodes include easy fabrication, uniform current distribution, and high packing density. However, they may suffer from low surface area, limiting the overall capacitance and energy storage capabilities.

TRIANGULAR ELECTRODE: A triangular electrode features a triangular shape with one or more pointed edges. This shape provides increased surface area compared to rectangular electrodes, resulting in higher capacitance and improved energy storage performance. Triangular electrodes can facilitate efficient ion diffusion and reduce the resistance of the electrode-electrolyte interface. They are often used in asymmetric supercapacitors to enhance specific energy.

SQUARE ELECTRODE: Similar to rectangular electrodes, square electrodes have straight edges but with equal dimensions on all sides. Square electrodes offer better surface area utilization compared to rectangular electrodes, leading to improved capacitance and energy storage. The square shape allows for a more uniform distribution of current, minimizing current crowding effects. Square electrodes are suitable for applications where space is a constraint.

SEMI-CIRCULAR ELECTRODE: A semi-circular electrode consists of a curved surface that resembles half of a circle. This shape provides a higher surface area compared to rectangular or square electrodes, leading to increased capacitance and energy storage capacity. The curved shape allows for efficient ion transport and reduces the distance for charge transfer, enhancing the overall performance of the supercapacitor. Semi-circular electrodes are often used to maximize surface area within limited space.

OTHER COMPLEX GEOMETRIES: In addition to the aforementioned basic shapes, supercapacitor electrodes can be designed with more complex geometries, such as interdigitated structures, fractal patterns, or hierarchical architectures. These complex geometries aim to further increase the effective surface area and promote ion diffusion, resulting in enhanced supercapacitor performance. These designs often require advanced fabrication techniques such as 3D printing or lithography.

The choice of electrode shape depends on specific application requirements, available fabrication methods, and desired performance parameters. Design considerations such as surface area, current distribution, and ease of fabrication should be taken into account when selecting the electrode shape for a supercapacitor.

3.5 IMPORTANCE OF ELECTRODE SHAPE

The shape of electrodes in supercapacitors plays a crucial role in determining their performance characteristics.

- Surface area
- Ion diffusion and accessibility
- Electrolyte penetration
- Electrode-electrolyte interface
- Structural integrity & packing density
- Manufacturing and scalability

The electrode shape directly affects the available surface area for charge storage. A larger surface area allows for more active sites for electrochemical reactions to occur, leading to higher capacitance and energy storage capacity. Electrodes with complex shapes or nanostructured surfaces can significantly increase the surface area, enhancing the overall performance of the supercapacitor.

The shape of the electrode influences the diffusion of ions within the electrode material and their accessibility to active sites. An optimized electrode shape can facilitate efficient ion diffusion and promote easy access to the electrode surface, resulting in faster charge and discharge rates. This leads to improved power density, making the supercapacitor suitable for applications that require rapid energy delivery.

The electrode shape also affects the penetration and distribution of the electrolyte within the electrode material. An electrode with an appropriate shape can ensure uniform electrolyte penetration, promoting effective ion transport and minimizing concentration gradients. This helps to maintain stable and consistent performance of the supercapacitor over multiple charge/discharge cycles.

The shape of the electrode influences the surface curvature and the distance between the electrode and the electrolyte. This, in turn, affects the electric field distribution at the electrode-electrolyte interface. An optimized electrode shape can maximize the electrode-electrolyte contact area, improving charge transfer kinetics and enhancing the overall efficiency of the supercapacitor.

Electrode shape is crucial for ensuring the structural integrity and stability of the supercapacitor. A well-designed electrode shape provides mechanical strength and supports the proper arrangement of electrode materials within the supercapacitor cell. It also allows for efficient packing of electrodes, which is important for achieving high energy density in practical supercapacitor designs.

The electrode shape should be considered during the fabrication process of supercapacitors. Certain shapes may be easier to fabricate, assemble, and scale up for mass production. Designing electrode shapes that are compatible with existing manufacturing techniques can lead to cost-effective production and commercial viability.

3.6 DESIGN AND SHAPING OF ELECTRODES:

The design and shaping of electrodes play a significant role in optimizing supercapacitor performance.

Electrode Geometry: The choice of electrode geometry depends on factors such as desired capacitance, specific power requirements, and ease of fabrication. Common shapes include rectangular, circular, triangular, and asymmetric designs.

Surface Area: Increasing the surface area of electrodes enhances the capacitance and energy storage capacity. Techniques such as nanostructuring, creating porous structures, or using hierarchical architectures can maximize the surface area.

Electrode Thickness: Controlling the electrode thickness is important for maintaining high ionic conductivity and reducing diffusion limitations. Thin electrodes allow for shorter ion diffusion paths, resulting in faster charge/discharge rates.

Alignment and Arrangement: In applications requiring stacked or multi-layered electrodes, proper alignment and arrangement are crucial to ensure uniform current distribution and optimal performance.

3.7 MATERIALS USED IN SUPER CAPACITOR

Fabrication of super capacitor is done by using a combination of materials like activated carbon, metal oxide, separator and electrolyte. Activated carbon and metal oxide are collectively known as electrode materials and are applied on the electrode base in the form of a paste.

Selection of Electrode Materials: The choice of electrode materials depends on the desired performance characteristics of the supercapacitor. Commonly used electrode materials include activated carbon, carbon nanotubes, graphene, metal oxides (such as RuO_2, MnO_2, or NiO), and conductive polymers. The selection is based on factors such as specific capacitance, electrical conductivity, stability, cost, and availability.

Carbon-Based Materials: Activated carbon, carbon nanotubes, and graphene are widely used due to their high surface area, good electrical conductivity, and chemical stability.

Metal Oxides: Metal oxides such as ruthenium oxide, manganese oxide, and nickel oxide exhibit pseudo capacitance, providing additional charge storage capacity.

Conductive Polymers: Polyaniline, polypyrrole, and polythiophene are examples of conductive polymers that offer high specific capacitance and good processability.

Composites: Composite electrodes combine multiple materials to take advantage of both double-layer capacitance and pseudo capacitance. For example, carbon-based materials can be combined with metal oxides or conductive polymers.

1. ELECTRODE MATERIALS:

Carbon-Based Materials:

- Activated Carbon: Activated carbon is widely used as an electrode material in supercapacitors due to its high surface area, porosity, and excellent electrical conductivity. It offers a large number of electrochemically active sites for charge storage.

- Carbon Nanotubes (CNTs): CNTs possess unique electrical and mechanical properties, making them suitable for supercapacitor applications. Their high surface area and superior conductivity contribute to improved energy storage capabilities.
- Graphene: Graphene, a single layer of carbon atoms arranged in a two-dimensional lattice, exhibits exceptional electrical conductivity, large surface area, and mechanical strength. Graphene-based electrodes enable high-performance supercapacitors.

Metal Oxides:

- Ruthenium Oxide (RuO_2): RuO_2 is a widely used pseudo capacitive electrode material due to its high specific capacitance, excellent conductivity, and good cycling stability. It enables supercapacitors with high energy density.
- Manganese Oxide (MnO_2): MnO_2 is another common metal oxide electrode material known for its low cost, abundance, and good capacitive properties. It offers a good balance between specific capacitance and cycling stability.
- Nickel Oxide (NiO): NiO exhibits high specific capacitance, good stability, and compatibility with various electrolytes, making it a favourable choice for supercapacitor electrodes.

2. SEPARATOR MATERIALS:

Separator materials are used to physically separate the positive and negative electrodes while allowing efficient ion transport. Commonly used separator materials include:

- **Polymer Separators:** Polymer materials such as polyethylene (PE), polypropylene (PP), and polyvinylidene fluoride (PVDF) are widely used due to their high ionic conductivity, mechanical strength, and chemical stability.

- **Ceramic Separators:** Ceramic materials like alumina (Al_2O_3) and zirconia (ZrO_2) offer higher thermal stability and better electrolyte compatibility compared to polymers. They are often used in high-temperature and high-power applications.

3. ELECTROLYTE:

Electrolytes play a vital role in the working of electrochemical super capacitor. Electrochemical energy is stored at the interface of electrode and electrolyte. The choice of electrolyte in super capacitor is as important as the choice of electrode material. Factors such as operating voltage, internal resistance and power density are strongly dependent on electrolyte conductivity. Some of the commonly used electrolytes for super capacitor are sulphuric acid, potassium sulphate and acetonitrile. 0.6 Molar potassium sulphate has been used in the research work presented. Supercapacitors can use water-based electrolytes, typically containing dissolved salts like potassium hydroxide (KOH) or sulphuric acid (H_2SO_4). Aqueous electrolytes are safer and less expensive but generally have a lower operating voltage.

Aqueous Electrolytes:

- Sulphuric Acid (H_2SO_4): Dilute sulphuric acid is commonly used as an aqueous electrolyte due to its good conductivity, low cost, and ease of handling. It is suitable for low-voltage supercapacitors.
- Potassium Hydroxide (KOH): KOH electrolyte is used in alkaline supercapacitors, offering higher conductivity and stability compared to sulphuric acid.

Organic Electrolytes:

- Acetonitrile (ACN): ACN-based electrolytes are widely used in organic solvent-based supercapacitors, offering high ionic conductivity and good electrochemical stability.
- Ionic Liquids: Ionic liquids, such as imidazolium or pyrrolidinium-based salts, provide wide electrochemical voltage windows, low volatility, and high thermal stability. They are used in advanced supercapacitor designs.

3.8 CHARACTERISTICS

HIGH POWER DENSITY: Supercapacitors have the ability to deliver and absorb high amounts of electrical power rapidly. They can provide quick bursts of energy and support high-power applications, making them suitable for applications that require rapid energy transfer.

RAPID CHARGE AND DISCHARGE: One of the notable features of supercapacitors is their ability to charge and discharge quickly. Unlike batteries, which may require hours for charging, supercapacitors can be charged within seconds or minutes, enabling rapid energy storage and release.

LONG CYCLE LIFE: Supercapacitors have an extended cycle life compared to batteries. They can endure a large number of charge-discharge cycles without significant degradation in performance. This longevity makes them suitable for applications that require frequent charging and discharging.

HIGH EFFICIENCY: Supercapacitors exhibit high energy efficiency due to their low internal resistance. They can efficiently store and release energy without significant energy losses, resulting in a high overall efficiency.

WIDE OPERATING TEMPERATURE RANGE: Supercapacitors can operate effectively across a wide range of temperatures, making them suitable for various environments and applications. They can function in extreme temperatures, both low and high, without significant impact on their performance.

SAFETY: Supercapacitors have inherent safety advantages compared to other energy storage devices, such as lithium-ion batteries. They are less prone to thermal runaway or explosion risks, making them a safer option in certain applications.

LOW SELF-DISCHARGE RATE: Supercapacitors have a relatively low self-discharge rate compared to batteries. They can retain stored energy for longer periods without significant loss, allowing for extended shelf life and readiness for immediate use.

SCALABILITY: Supercapacitors offer scalability in terms of energy and power requirements. They can be designed and configured in various sizes and capacitance ranges to meet specific application needs.

ENVIRONMENTAL FRIENDLINESS: Supercapacitors are generally considered more environmentally friendly than some other energy storage technologies. They do not contain toxic or hazardous materials, and some types can be recycled.

COMPLEMENTARY TO OTHER ENERGY STORAGE SYSTEMS: Supercapacitors can be used in conjunction with other energy storage systems, such as batteries or fuel cells, to enhance overall system performance. They can provide quick power bursts during high-demand situations or act as energy buffers to improve system efficiency.

3.9 ACTUAL SUPERCAPACITOR MODEL

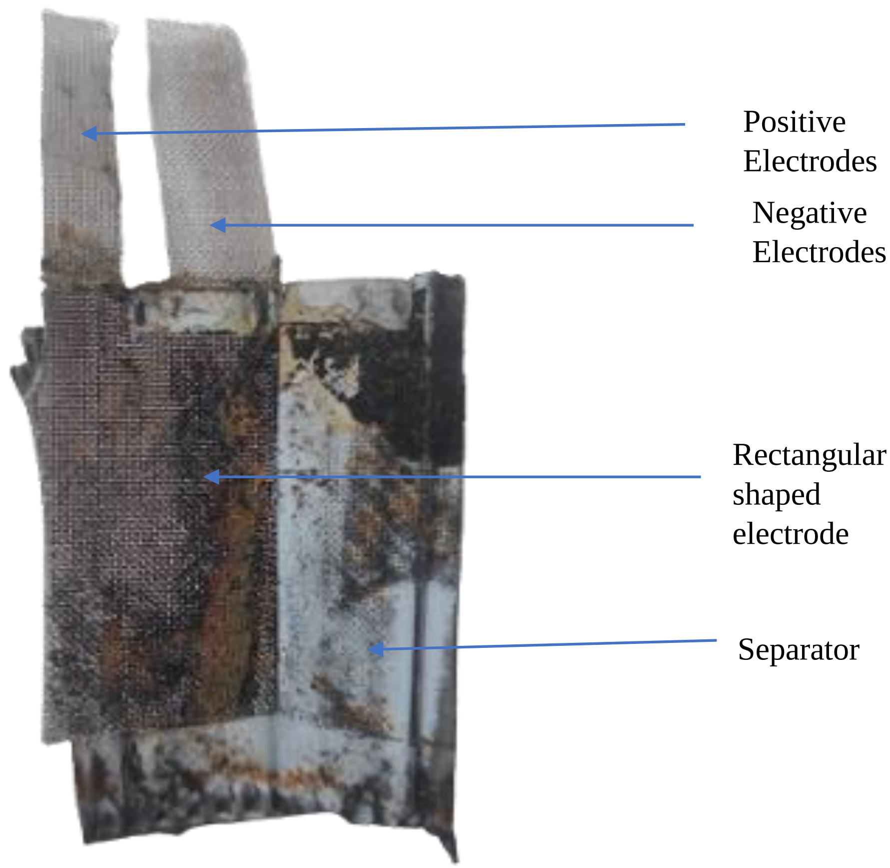


FIG 3.1. INTERNAL STRUCTURE OF SUPERCAPACITOR

3.10 FORMATION OF SUPERCAPACTIOR OF DIFFERENT SHAPES:

One may detect a change in capacitance as the electrode's shape changes. The forms of an electrode include a circle, a semicircle, a triangle, a rectangle, a square, and a rhombus. Making electrodes frequently uses rectangular shapes. These supercapacitor's can be used to line the inside walls of vehicles such as the space shuttle and aeroplanes. Supercapacitors with a square shape can be stacked. Specific uses are possible for semi-circular supercapacitors. The versatility of the system is increased by using multiple forms for different purposes. To provide a point of reference, the electrode base area for each of these shapes is held constant at 3 square cm. Four electrode shapes are included in Table 1 along with their measurements.

Shape	Dimensions (in cm)
Rectangle	Length: 3,Breadth: 1
Square	Side: 1.73
Triangle	Base : 2, Height: 3
Semicircle	Radius:1.4

Table 3.1. Various shapes used to make electrode of supercapactior

RECTANGULAR SUPERCAPACITOR:

Electrode Fabrication: Prepare rectangular-shaped electrodes by depositing the desired electrode material onto a substrate using techniques such as screen printing, spray coating, or electrode position. The substrate can be a rigid material like glass or a flexible material like a plastic film.

Separator Placement: Cut a separator material into a rectangular shape that matches the dimensions of the electrodes. Place the separator between the positive and negative electrodes to prevent electrical contact.

Electrode Stacking: Stack the electrodes and separator in an alternating fashion, ensuring proper alignment and complete coverage.

Current Collector Attachment: Connect current collectors (aluminium or copper foils) to the electrodes, allowing for efficient current flow.

Electrolyte Introduction: Introduce the electrolyte solution into the assembled supercapacitor cell, ensuring it fully impregnates the electrodes and separator.

Encapsulation: Enclose the assembled supercapacitor components within a suitable housing or package to protect against environmental factors.

SQUARE SUPERCAPACITOR:

The formation process for a square-shaped supercapacitor is similar to that of a rectangular supercapacitor, with the main difference being the electrode and separator shapes, which should be square instead of rectangular.

SEMI-CIRCULAR SUPERCAPACITOR:

Electrode Fabrication: Fabricate semi-circular-shaped electrodes by depositing the electrode material onto a substrate. This can be achieved by using a mask or stencil during the deposition process.

Separator Placement: Cut a separator material into a semi-circular shape that matches the dimensions of the electrodes. Place the separator between the positive and negative electrodes.

Electrode Stacking: Stack the electrodes and separator, aligning the semi-circular shapes to form a complete supercapacitor cell.

Current Collector Attachment: Attach current collectors to the electrodes to facilitate current flow.

Electrolyte Introduction: Introduce the electrolyte solution into the assembled supercapacitor cell, ensuring proper impregnation.

Encapsulation: Enclose the assembled components in a suitable housing for protection.

TRIANGULAR SUPERCAPACITOR:

Electrode Fabrication: Prepare triangular-shaped electrodes using deposition techniques. This can involve using a mask or stencil with a triangular pattern during the deposition process.

Separator Placement: Cut a separator material into a triangular shape that matches the electrode dimensions. Place the separator between the positive and negative electrodes.

Electrode Stacking: Stack the triangular electrodes and separator in the desired arrangement, ensuring proper alignment.

Current Collector Attachment: Connect current collectors to the electrodes.

Electrolyte Introduction: Introduce the electrolyte solution into the assembled supercapacitor cell.

Encapsulation: Enclose the assembled components within a suitable housing. All materials and parameters—aside from electrode shape—are kept precisely the same in order to create supercapacitors using various electrode forms. Here are some of them:

- The electrode base is constructed from a 3 square cm piece of stainless steel wire mesh.
- Aqueous paste with 0.60g of activated carbon and ethanol (solvent) is applied to a cathode plate.
- Aqueous paste with 0.30g of activated carbon, 0.30g of manganese dioxide, and ethanol (solvent) is added to the anode plate.
- 11.3g potassium sulphate is used as electrolyte with molarity 0.73 Molar.
- Supercapacitor is charged to a maximum voltage of 2.20 V.

The stainless steel wire mesh is properly limited for the extraction of the electrode base. Two electrodes are removed from the gauge for one supercapacitor, and one electrode the cathode plate has an appropriate mixture of activated carbon and ethanol put to it. An appropriate paste of activated carbon, MnO_2, and ethanol is applied to the anode plate-shaped electrode on the opposite electrode. Utilising a polyethylene separator, these electrodes are separated. For the separators, adhesive (favibond) is used to stick them. Following the sticking, a pressing method is used to keep the electrolyte and electrodes apart.

Testing of supercapacitor: Supercapacitor testing may be done by charging and draining the supercapacitor. In the actual setup for supercapacitor charging and discharging, the supercapacitor is immersed in a solution of K2SO4 and then charged. Before being attached to the dc source to start charging, the supercapacitor is totally immersed in K2SO4 solution for 3 minutes. The supercapacitor is charged for one minute using 2 volts from a dc source. After the supercapacitor has been fully charged, it is drained by placing a voltmeter across it. As the supercapacitor is being discharged, the discharging current is measured.

Charging / Discharging Circuit:

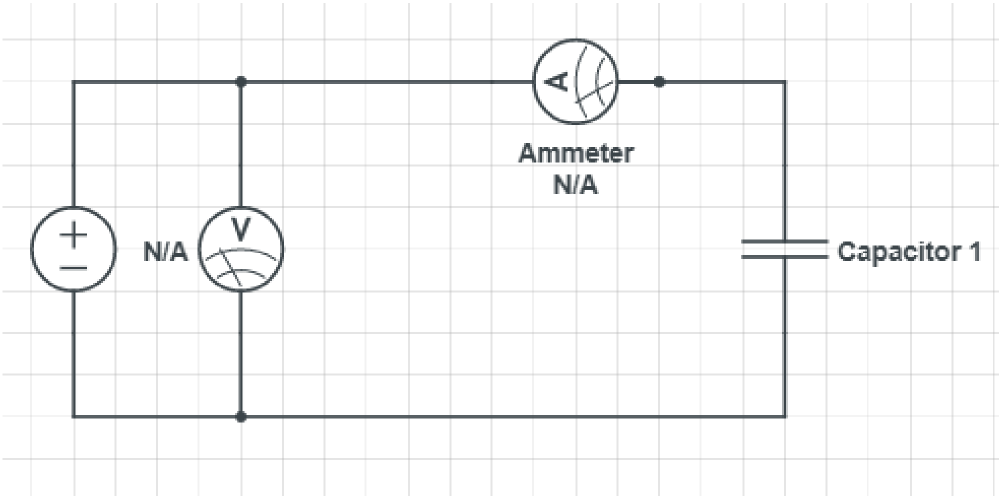


Fig 3.2a. Charging Circuit

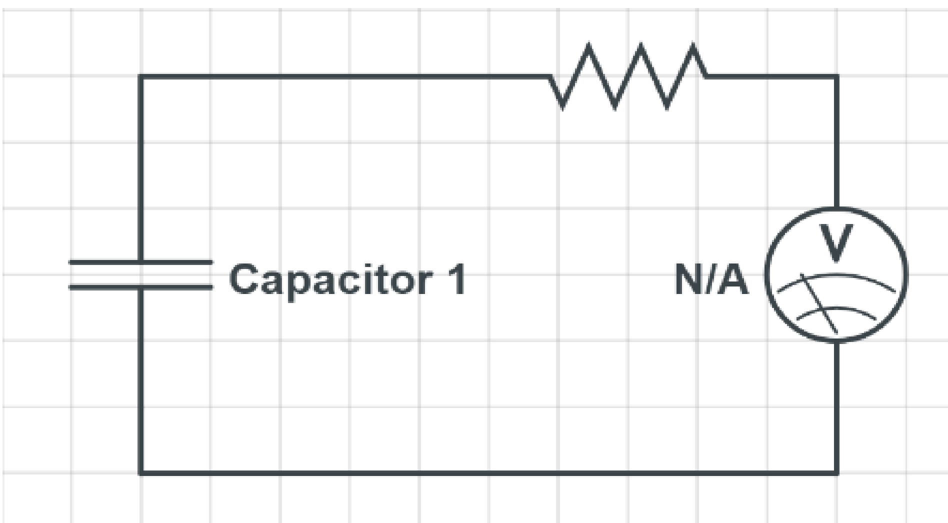


Fig 3.2b. Discharging Circuit

CHAPTER 4

EXPERIMENTAL SETUP:

The experimental setup for the design and fabrication of a supercapacitor involves several key components and steps.

MATERIALS AND EQUIPMENT:

- Electrode Materials: Select the desired electrode materials based on the application requirements. This can include carbon-based materials, metal oxides, conductive polymers, or composites.
- Substrates: Choose suitable substrates for electrode deposition, such as glass, silicon, or flexible substrates like plastic films.
- Current Collectors: Aluminium or copper foils are commonly used as current collectors.
- Separator: Select a porous separator material that allows for ion transport while preventing electrical contact between the electrodes.
- Electrolyte: Choose an appropriate electrolyte solution based on the specific voltage range, temperature stability, and energy requirements.

ELECTRODE FABRICATION:

- Electrode Deposition: Use techniques like screen printing, spray coating, or electrode position to deposit the electrode material onto the substrate. The specific method depends on the material and desired electrode geometry.
- Electrode Drying and Annealing: Dry the deposited electrode material and perform annealing if required to enhance its electrical conductivity and stability.
- Electrode Nano structuring (Optional): Utilize techniques like electrochemical etching or sol-gel methods to create nanostructured surfaces for increased surface area and improved charge storage.

SUPERCAPACITOR ASSEMBLY:

- **Separator Placement:** Carefully place the separator material between the positive and negative electrodes to prevent electrical short circuits while allowing ion transport.
- **Electrode Stacking**: Stack the electrodes with the separator in between, ensuring proper alignment and arrangement.
- **Current Collector Attachment**: Connect the current collectors (aluminium or copper foils) to the electrodes, allowing for efficient current flow.
- **Encapsulation**: Optionally encapsulate the assembled supercapacitor components within a suitable housing or package to protect against environmental factors.

ELECTROLYTE INTRODUCTION:

- **Electrolyte Filling:** Introduce the selected electrolyte solution into the assembled supercapacitor cell. Ensure proper impregnation of the electrodes and separator for effective ion transport.

PERFORMANCE EVALUATION:

- **Characterization:** Perform various tests to evaluate the supercapacitor's performance, such as cyclic voltammetry, galvanostatic charge-discharge cycling, impedance spectroscopy, and capacitance measurement.
- **Data Analysis**: Analyse the obtained data to assess key performance parameters like specific capacitance, energy density, power density, cycling stability, and efficiency.

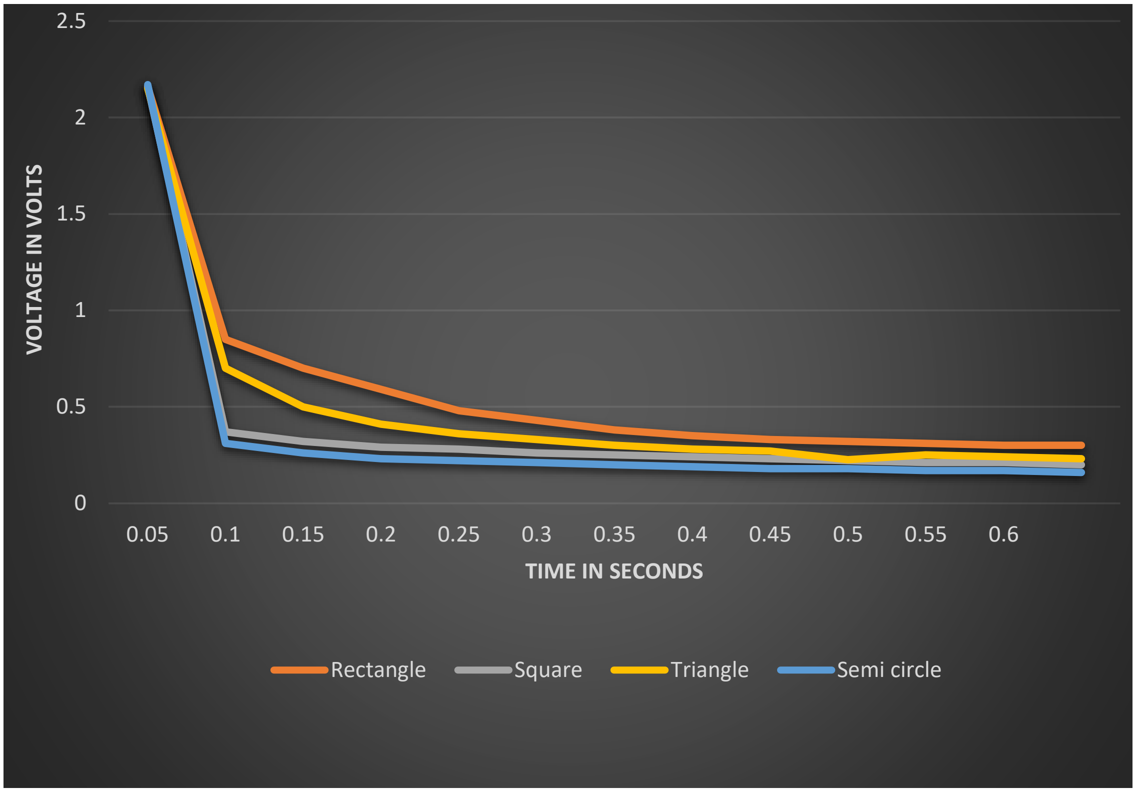
The specific details of the experimental setup may vary based on the electrode materials, fabrication techniques, and equipment available. Additionally, safety precautions should be followed when handling chemicals, working with electrical components, and operating any required instruments.

CHAPTER 5

RESULTS AND GRAPHS

Time in seconds	Voltage (in volts)			
	Rectangle	**Square**	**Triangle**	**Semi-circle**
0	2.16	2.16	2.15	2.17
5	0.85	0.37	0.7	0.31
10	0.7	0.32	0.5	0.26
15	0.59	0.29	0.41	0.23
20	0.48	0.28	0.36	0.22
25	0.43	0.26	0.33	0.21
30	0.38	0.25	0.3	0.2
35	0.35	0.24	0.28	0.19
40	0.33	0.23	0.27	0.18
45	0.32	0.22	0.226	0.18
50	0.31	0.21	0.25	0.17
55	0.3	0.21	0.24	0.17
60	0.3	0.2	0.23	0.16

Table.5.1 Time and voltage reading of actual performances



Graph: Discharging graph of all shape of supercarpacitor

CHAPTER 6

CONCLUSION & FUTURE SCOPE

6.1 CONCLUSION:

The study and analysis of the shape of electrodes implemented in supercapacitors for application in load have provided valuable insights into the design and fabrication aspects of these energy storage devices. By exploring various electrode shapes such as rectangular, square, semi-circular, and triangular, the project aimed to understand their impact on the performance and efficiency of supercapacitors.

Rectangular shaped electrode supercapacitor has the ability to hold large charges. The largest amount of capacitance is produced by the electrode's rectangular form due to its slow rate of discharge. In comparison to other electrode shapes used in supercapacitors, the rectangular electrode has a high energy storage capacity and a high capacitance value of 4.60 micro farad. Additionally, because it often has a rectangular design, it takes less time to execute.

6.2 FUTURE SCOPE

1) The project primarily focuses on the impact of electrode shape on supercapacitor performance. Further research can explore the use of advanced electrode materials, such as graphene, carbon nanotubes, or metal organic frameworks, to enhance the energy storage capacity and performance of supercapacitors. Investigating new materials and their compatibility with different electrode shapes can lead to significant advancements in supercapacitor technology.
2) The application of nanotechnology can play a significant role in enhancing the performance of supercapacitors. Future research can explore the use of nanoscale materials and nanostructuring techniques to further improve the specific capacitance, energy density, and power density of supercapacitors. Nanoscale electrode shapes and structures can offer enhanced surface area, ion transport, and charge storage capabilities.
3) The integration of supercapacitors with other energy storage systems, such as batteries or fuel cells, can lead to the development of hybrid energy storage systems with improved overall performance. Future research can focus on optimizing the design and control strategies for integrating supercapacitors with other energy storage technologies, enabling efficient energy management, and enhancing the overall energy storage capabilities.
4) While the project focuses on the design and fabrication of supercapacitors at the laboratory scale, future research can explore the scaling up and manufacturing processes for mass production. Developing scalable fabrication techniques, optimizing electrode shaping methods, and ensuring consistency and quality control in large-scale production are essential aspects to consider for practical implementation of supercapacitors.

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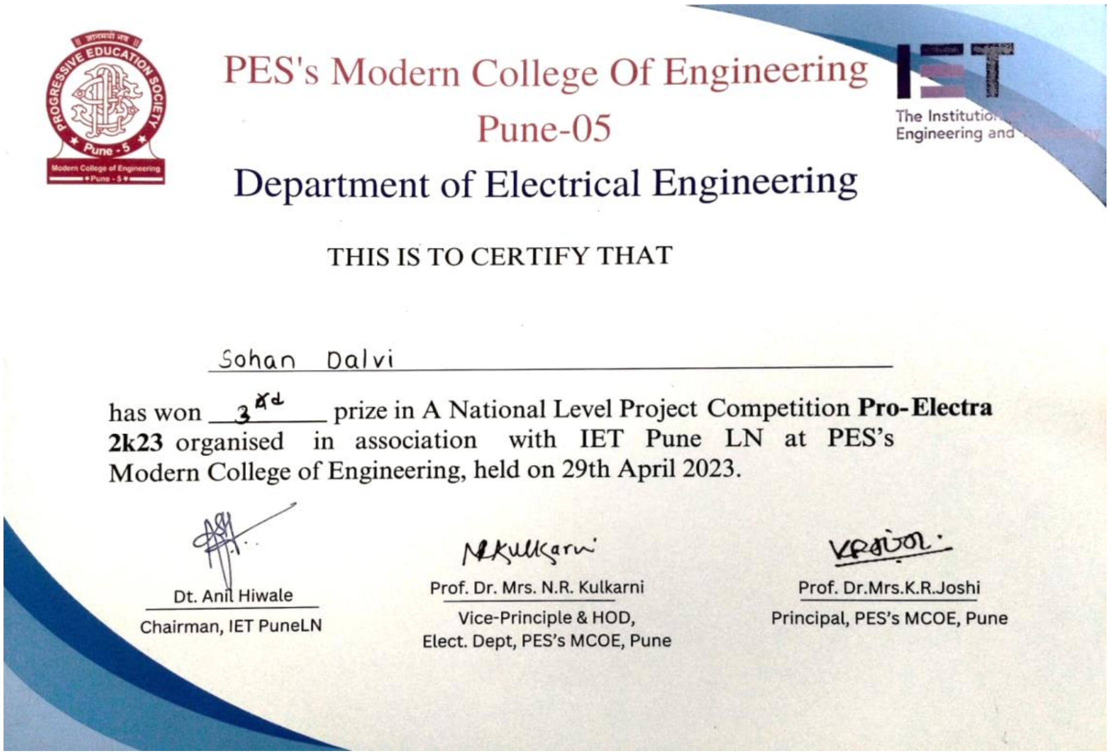

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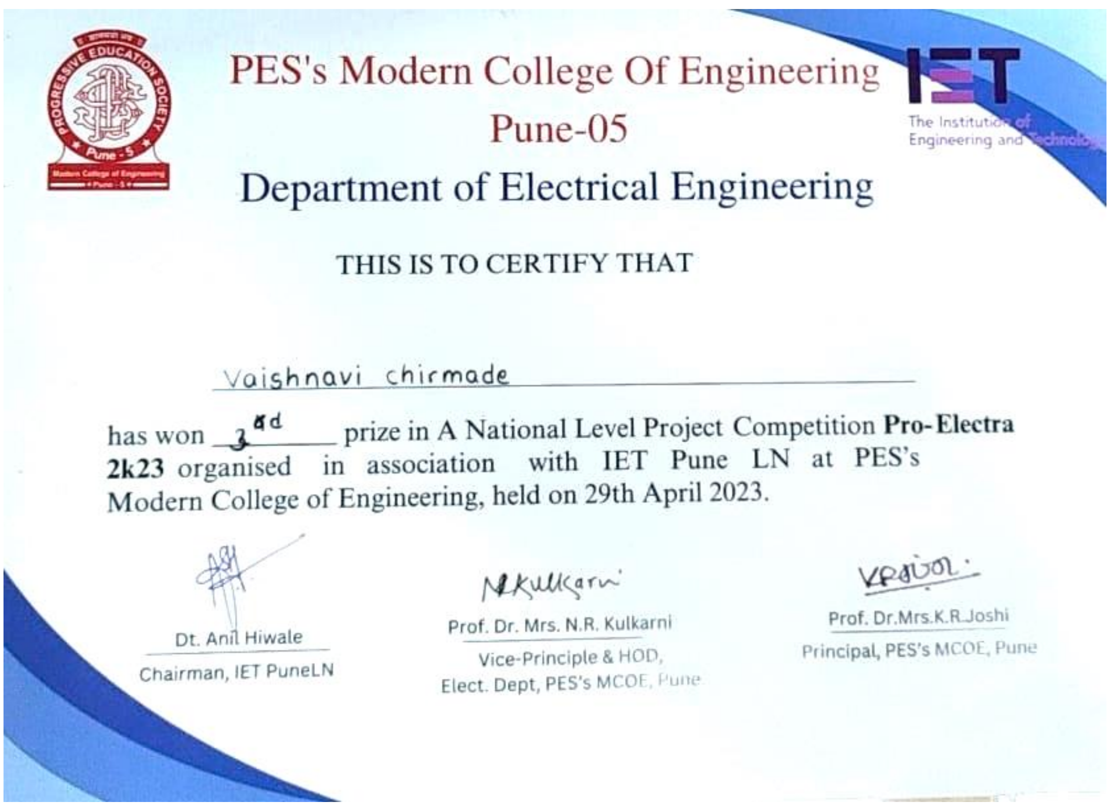

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