# Final Year Project Showcase Batch-2019
# Year 2023

<table>
<tr><td colspan="2">Department: Electronics Engineering<br>Programme: Electronics Engineering</td></tr>
<tr><td>1</td><td>Project Idea<br><br><u>Project Title:</u> Development and Assessment of Electrodes via Electrochemical Impedance Spectroscopy.<br><u>Project Description:</u> The goal of the project is to build a supercapacitor device using electrodes coated with carbon conductive ink through deposition techniques such as doctor blading and dip coating. This supercapacitor device is intended to be capable of powering an LED.<br><u>Key Information:</u><br>Supercapacitor Device: It will utilize electrodes coated with carbon conductive ink.<br>Coating Techniques: Doctor blading and dip coating will be employed in the electrode fabrication.<br><u>Application:</u> The device's primary function is to switch an LED.<br><u>Collaborators:</u><br>Electronic Department: Collaborating on the project for electronic expertise and research.<br>Metallurgy Department:Collaborating for access to their labs, particularly for etching processes.<br>Food Department:Collaborating for access to labs for preparing the conductive ink and deposition techniques.</td></tr>
<tr><td>2</td><td>Process<br><br>The first and the basic step of the project is the preparation of carbon ink using Activated Carbon, Graphite, Polyvinylidene Fluoride (PVDF) and N-Methyl Pyrrolidene (NMP). After ink preparation, 204 Stainless Steel was used as substrate and cut into several little samples of $1 \times 2\ cm^2$ area. Then the pieces of stainless steel were prepared by etching and cleaning with different chemicals such as Ethanol and Iso-propyl alcohol. Once samples were ready, the coating process was started. Two different ink deposition techniques were utilized on samples Doctor Blading and Dip Coating.  After coating, the samples were placed in the oven at 60°C for two hours to dry. The coating should be perfect for the electrons to flow flawlessly and produce accurate EIS results.<br>Electrochemical Impedance Spectroscopy (EIS) serves as a robust method for deducing material properties and examining electrode reactions. This characterization technique is remarkably sensitive, enabling the assessment of the electrical behavior of chemical systems without causing any damage. EIS was performed on samples of Dip Coating and Doctor Blading. The results obtained are in the form of Nyquist and Bode plots. Nyquist plot combines phase and gain into one plot whereas Bode plot is characterized into two, one for phase and one for gain (or magnitude). After the characterization of electrodes via EIS the electrodes were used for the development of supercapacitor device.</td></tr>
<tr><td>3</td><td>Outcome<br><br>Following are the results of the ink coated samples using Electrochemical Impedance Spectroscopy.</td></tr>
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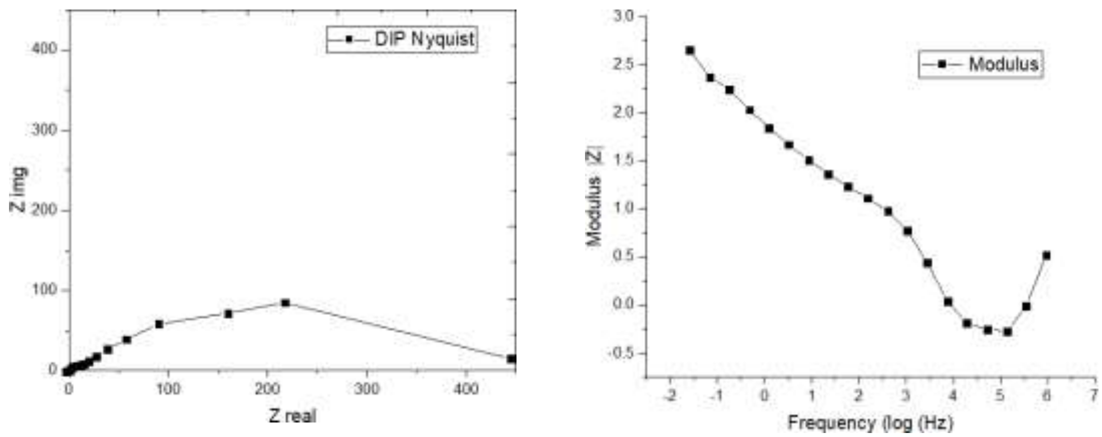


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**Fig1 (a) Nyquist Plot (b) Bode Plot of Dip Coated Sample**

The EIS results of a dip-coated sample are depicted above. In Fig1(a), the Nyquist plot is illustrated, where the real impedance is shown on the X-axis and the imaginary impedance on the Y-axis. A semi-circle represents the equivalent series resistance (R_ESR). Both the X-axis and Y-axis have a range from 0 to 500.
In Fig1(b), the Bode plot is presented, with the X-axis representing frequency and the Y-axis representing the modulus. The frequency range spans from -2 to 7, while the modulus range is from -0.5 to 3.

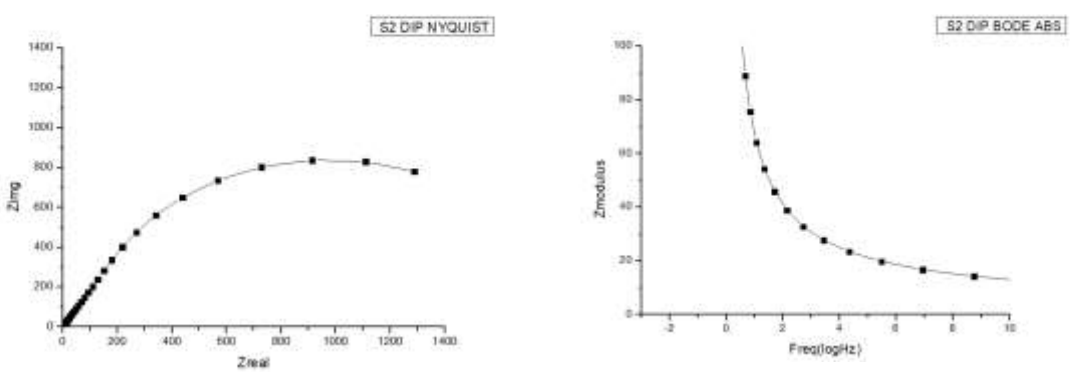


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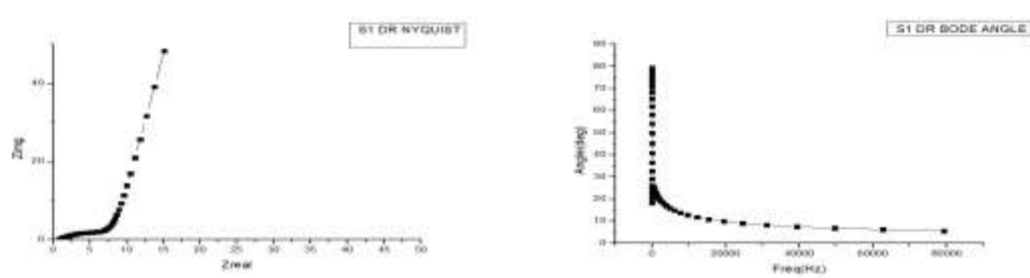
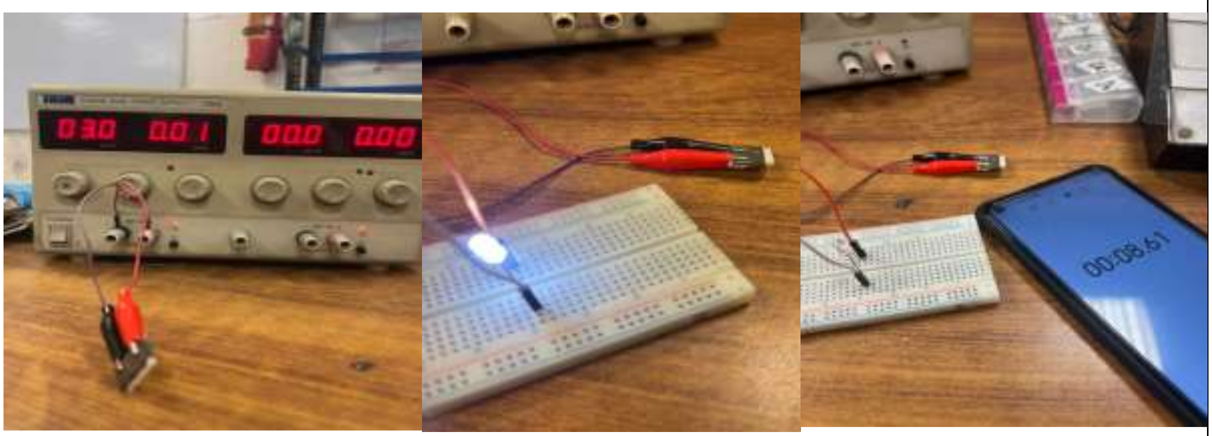
**Fig2 (a) Nyquist Plot (b) Bode Plot of Dip Coated Sample**




**a b**

**Fig3 (a) Nyquist Plot (b) Bode Plot of Dr Bladed Sample**

Figures 2(a) and 3(a) illustrate the Nyquist plots for the Dip Coating and Doctor Blade (Dr. Blade) samples, respectively. In these plots, the semi-circle signifies the solution resistance, while the straight line corresponds to the Warburg impedance (W). The Warburg impedance is indicative of slower reactions such as diffusion.
Bode Absolute and Bode Angle outcomes are presented for the Dip Coated and Dr. Blade samples in Figures 2(b) and 3(b). While both outcomes employ frequency on the X-axes, the Y-axis differs between the two. For the Dip sample, the Y-axis represents Z modulus, whereas for the Dr. sample, it represents the angle.
After the development of Supercapacitor, testing procedure was performed. A clip is used to hold the supercapacitor device tightly. The testing of SC device is performed in such a way that the crocodile side of two leads is attached to the supercapacitor ends and the other sides are provided with the voltages from the power supply as shown in Fig4 (c). The red lead is given 3 volts and the black lead with negative voltage. In this way the SC device is charged within 5 to 10 minutes. Now the leads are disconnected and one side of the leads are attached with the LED legs (negative voltage for short leg and positive voltage for long). The timer is set and the lead is on for 8 sec as shown in Fig4 (b) and (c). Finally, the designed SC delivers power to LED for a short period of time.




a b c

**Fig4 (a) Charging process of Supercapacitor (b) LED response (c) LED discharge**

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**Evidence (Theoretical Basis)**

World is moving towards renewable energy and electric vehicles where supercapacitors, batteries and solar cells are being used. Supercapacitor is the device composed of different layers where the electron should flow from one electrode to another electrode. The electron will face different form of resistances in its path. The main problem is to provide ease in flow of electrons among different layers of device. Electrodes are important part of charge generation and charge storage devices. They collect electrons from circuit and catalyses' redox reduction in the electrolyte. It has a significant impact on the performance, stability and cost of the devices. The movement of electrons in a redox reaction can be studied using different electrochemical techniques such as Electrochemical Impedance Spectroscopy (EIS), Cyclic Voltammetry (CV), Chronopotentiometry etc. where a certain range of potential is applied and the current response is measured.

Our primary objective of this project is to study the quality of electrode and what role does it play in the flow of electrons, this can be done by Electrochemical Impedance Spectroscopy. EIS is an extremely powerful technique which provides detailed information

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| | about the Battery's State of Health but requires long rest times to prevent the battery relaxation effect from impacting the EIS measurement. It realizes the rapid estimation of the State of Health of batteries through the mathematical model established by the constant phase element parameters in the constructed EIS equivalent circuit model and the Battery's State of Charge (SoC) and State of Health (SoH).<br>We used two deposition techniques Dip Coating and Doctor Blading for the development of electrodes.<br><br>Calculations were performed for Nyquist and Bode plots. The electrodes were utilized for fabrication of supercapacitor. The proof of concept is achieved by LED glow using developed supercapacitor device. |
| **5** | **Competitive Advantage or Unique Selling Proposition** (Cost Reduction, Process improvement, Attainment of any SDG (Sustainable Development Goal), increase of market share or capturing new market or having superior performance over a competitor. In summary, any striking aspect of the project that compels the industry to invest in FYP or purchase it. Some detailed description is required in terms of how, why when what. You can select one or more from the following dropdown and delete the rest of them). Please keep relevant options, delete the rest of them, and correct the sequence |
| **a** | **Attainment of any SDG** (e.g. How it is achieved and why it is necessary for the region)<br>• **SDG#07: Affordable and Clean Energy**<br>• **SDG# 09; Industry, Innovation and Infrastructure**<br>• **SDG#11: Sustainable Cities and Communities**<br>• **SDG#12: Responsible Consumption and Production** |
| **b** | **Any Environmental Aspect** (e.g. carbon reduction, energy-efficient, etc.)<br>Supercapacitors, also known as ultracapacitors have several environmental aspects that make them an interesting choice for energy storage solutions. Here are some key environmental aspects of supercapacitors:<br>• Energy Efficiency: Supercapacitors are highly efficient in terms of energy storage and discharge. They have low internal resistance, which means they can quickly charge and discharge energy without significant energy losses. This efficiency helps reduce overall energy consumption and greenhouse gas emissions, particularly in applications where rapid energy cycling is required.<br>• Longevity: Supercapacitors have a longer lifespan compared to many other energy storage technologies, such as batteries. This longevity reduces the frequency of replacement and disposal, which can be environmentally taxing.<br>• Low Toxicity: Supercapacitors typically use non-toxic materials in their construction, such as activated carbon or other carbon-based materials for electrodes and an electrolyte solution. This reduces the risk of environmental contamination from hazardous chemicals.<br>• Energy Storage for Renewables: Supercapacitors can help stabilize the output of intermittent renewable energy sources like solar and wind power. Their quick response time and ability to handle rapid charge and discharge cycles make them suitable for smoothing out fluctuations in the grid, reducing the need for fossil fuel backup power plants.<br>• Reduced Energy Waste: Supercapacitors can be used in conjunction with batteries to improve energy system efficiency. They can handle short-duration, high-power demands, reducing the strain on batteries and extending their lifespan, which can ultimately reduce the environmental impact associated with battery production and disposal.<br>While supercapacitors offer several environmental benefits, it's essential to consider the entire life cycle of these devices, including manufacturing processes and end-of-life disposal or recycling, to assess their overall environmental impact accurately. Additionally, ongoing research and development in supercapacitor technology may further enhance their environmental performance in the future. |
| **c** | **Cost Reduction of Existing Product**<br>Reducing the cost of supercapacitors is crucial for making them more competitive with other |

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| | energy storage technologies like batteries and for facilitating their broader adoption in various applications. Here are several strategies and factors that can contribute to the cost reduction of supercapacitors:<br>• Improved Materials and Manufacturing Processes: Developing more cost-effective electrode materials and electrolytes can significantly reduce production costs.<br>• Energy Density Enhancement: Increasing the energy density of supercapacitors, which is currently lower than batteries, can reduce the number of supercapacitor cells needed for a given application. This can lead to cost savings by using fewer materials and components.<br>• Integration with Batteries: Combining supercapacitors with batteries in hybrid energy storage systems can improve overall system performance while reducing the size and capacity requirements of both components. This integration can lead to cost savings in terms of materials and manufacturing.<br>• Recycling and Reuse: Developing effective recycling processes for supercapacitors can recover valuable materials and reduce the environmental impact of disposal. Reusing components from old supercapacitors in new ones can also save costs.<br>• Advanced Electrode Fabrication Techniques: Utilizing advanced manufacturing techniques such as 3D printing or roll-to-roll processing can streamline production and reduce labor and material costs.<br>• Innovative Electrode Materials: Exploring new electrode materials that are abundant, low-cost, and exhibit excellent performance characteristics can help reduce material costs.<br>• Design Optimization: Optimizing the design of supercapacitor cells and modules for specific applications can reduce the overall cost of the system by minimizing the number of cells required and maximizing efficiency. |
| **d** | **Process Improvement which Leads to Superior Product or Cost Reduction, Efficiency Improvement of the Whole Process** (e.g. What is the issue is current process and what improvement you suggests)<br>Preparation of ink and coating techniques are major challenges. In assessment, it appears that a promising avenue for addressing these difficulties involves the exploration and implementation of alternative strategies.<br>Firstly, spin coating can be considered as an alternative technique. Spin coating is known for its precision and uniformity in applying thin films, which could potentially provide a solution to the uneven coating issues we've encountered thus far. This method offers the advantage of consistent and controlled deposition, making it a viable candidate for refining processes.<br>Additionally, modifications can be made in the composition of ink. Adjusting the recipe could potentially lead to improved adhesion, viscosity, or other properties crucial for successful coatings. This approach involves a systematic review of the ink's constituents and proportions to optimize its performance, addressing one of the root causes of challenges.<br>Furthermore, exploring the possibility of altering the size of electrodes used in the project can be another milestone. Adjusting electrode dimensions can impact various aspects of the process, including the distribution of materials during coating. By carefully investigating and experimenting with different electrode sizes, it is aimed to find an optimal configuration that enhances the overall quality and efficiency of coatings.<br>In summary, significant challenges related to ink and coating techniques can be effectively addressed through the adoption of alternative methods like spin coating, fine-tuning the ink recipe, and experimenting with electrode size adjustments. These strategies represent a proactive approach to refining our processes and achieving the desired project outcomes. |
| **e** | **Expanding of Market share** (e.g. how it expand and what is the problem with the current market<br>Expanding the market share of supercapacitors involves addressing various challenges and opportunities in the current market. Here are some strategies and considerations for expanding the market share of supercapacitor devices:<br>1. Diversify Applications:<br>• Identify New Applications: Explore and identify emerging applications and industries |

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| | where supercapacitors can provide unique benefits. This could include sectors like renewable energy, aerospace, medical devices, and more.<br>• Customization: Develop customizable solutions for specific applications to meet the unique requirements of different industries. Tailoring supercapacitors to specific needs can create new market opportunities.<br><br>2. Improve Performance Metrics:<br>• Energy Density: Continue research and development efforts to improve the energy density of supercapacitors. This is a critical factor in expanding their use beyond high-power, short-duration applications.<br>• Cycle Life: Extend the cycle life of supercapacitors to make them more cost-effective and durable in long-term applications.<br>• Temperature Range: Enhance the temperature range within which supercapacitors can operate effectively to make them suitable for more extreme environments.<br><br>3. Integration with Other Technologies:<br>• Hybrid Systems: Explore ways to integrate supercapacitors with other energy storage technologies like batteries to create hybrid systems that offer the advantages of both.<br>• Internet of Things (IoT): Develop supercapacitor-based energy storage solutions for IoT devices to enhance their power efficiency and reduce the need for frequent battery replacements.<br><br>4.Collaborate and Partner:<br>• Industry Collaboration: Collaborate with other companies and research institutions to pool resources and expertise in advancing supercapacitor technology and its applications.<br>• Strategic Partnerships: Establish partnerships with key players in industries that could benefit from supercapacitor technology, such as automotive manufacturers or renewable energy companies.<br><br>5.Address Challenges:<br>• Energy Density Gap: Continuously work on addressing the energy density gap between supercapacitors and batteries, especially in applications where high energy capacity is essential.<br>• Market Maturity: Recognize that the supercapacitor market is still evolving, and adoption may be slower in some industries due to established technologies and infrastructure. |
| **f** | **Capture New Market** (e.g. Niche market or unaddressed segment)<br>Capturing new markets for supercapacitor devices often involves identifying niche markets or unaddressed segments where supercapacitors can offer unique advantages. Here are some potential niche markets and strategies for entering them:<br><br>• Portable Medical Devices:<br>Niche Market: Develop supercapacitors tailored for portable medical devices, such as insulin pumps or wearable defibrillators. These devices require compact and reliable energy storage solutions.<br>Advantages: Supercapacitors can offer long cycle life, quick charging, and small form factors, making them suitable for medical applications where reliability and size are critical.<br><br>• Wearable Technology:<br>Niche Market: Develop supercapacitors for high-end wearable technology, such as augmented reality (AR) glasses and smart clothing. |

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| | Advantages: Supercapacitors can provide fast charging for wearables, reducing downtime and enhancing user experience. They can also extend battery life in wearables with power-hungry features.<br><br>• Public Infrastructure:<br>Niche Market: Target the public infrastructure sector for applications like smart traffic management systems and street lighting.<br>Advantages: Supercapacitors can store and release energy quickly, making them ideal for handling short-term energy spikes and grid stabilization in smart city applications.<br><br>• Energy Harvesting:<br>Niche Market: Focus on applications where energy harvesting from ambient sources (such as solar, kinetic, or thermal energy) is essential, such as wireless sensors in remote locations.<br>Advantages: Supercapacitors can efficiently store and release energy from intermittent sources, ensuring uninterrupted operation of remote sensors and devices.<br>• Emergency Lighting:<br>Niche Market: Offer supercapacitor-based emergency lighting solutions for commercial buildings, hospitals, and public spaces.<br>Advantages: Supercapacitors can provide rapid, reliable illumination during power outages, ensuring safety and security in critical environments.<br><br>• Construction and Heavy Equipment:<br>Niche Market: Address the construction industry's need for energy storage in heavy machinery and equipment, enabling efficient hybrid systems.<br>Advantages: Supercapacitors can enhance the power output of heavy equipment during peak demands, reducing fuel consumption and emissions. |
| **6** | **Target Market** (Industries, Groups, Individuals, Families, Students, etc) Please provide some detail about the end-user of the product, process, or service<br>Supercapacitors have a wide range of potential target markets and end-users due to their versatility in energy storage and rapid energy discharge. Here are some key industries and groups that often utilize or benefit from supercapacitors:<br><br>• Automotive Industry:<br>Electric Vehicles (EVs): Supercapacitors are used in electric and hybrid vehicles for regenerative braking, improving energy efficiency, and providing quick bursts of power for acceleration.<br>Start-stop Systems: Supercapacitors can enhance start-stop systems in traditional combustion engine vehicles, reducing fuel consumption and emissions.<br><br>• Transportation and Mass Transit:<br>Public Transportation: Supercapacitors are employed in buses and trams for regenerative braking and quick charging at stops, reducing energy consumption and emissions.<br>Railway Systems: Supercapacitors help improve the energy efficiency and reliability of trains.<br><br>• Renewable Energy:<br>Energy Storage: Supercapacitors are used in conjunction with renewable energy sources like solar and wind to store excess energy and provide rapid power output when needed.<br><br>• Industrial Automation:<br>Robotics: Supercapacitors provide quick bursts of power to robotic systems, improving their agility and efficiency.<br>Factory Automation: Supercapacitors help manage power fluctuations and provide backup power in industrial settings. |

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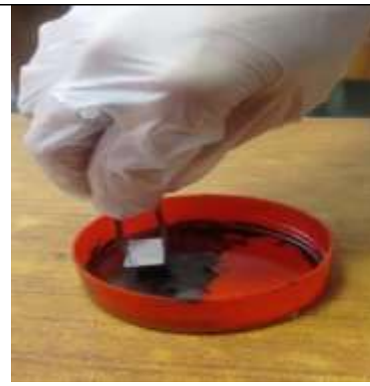
| | • Aerospace and Defense:<br>Satellites: Supercapacitors are used in satellites and spacecraft for energy storage and rapid power delivery during maneuvers.<br><br>• Renewable Energy Storage Solutions:<br>Grid Stabilization: Supercapacitors can support grid stabilization by providing rapid response to fluctuations in supply and demand.<br><br>• Data Centers and IT Infrastructure:<br>Backup Power: Supercapacitors are employed for short-term backup power in data centers, ensuring uninterrupted operation during power outages.<br>• Medical Devices:<br>Implantable Devices: Supercapacitors can be used in medical implants, such as pacemakers and neurostimulators, to provide reliable and long-lasting energy storage.<br><br>• Research and Development:<br>Scientists and Engineers: Researchers and engineers use supercapacitors in various experiments and prototyping efforts.<br><br>Supercapacitors continue to be an area of active research and development, making them a promising energy storage solution for a wide range of applications. | |
| **7** | **Team Members** (Names along with email address) | Aleena Ali<br>ali4204883@cloud.neduet.edu.pk<br>Hira Shiraz<br>shiraz4205626@cloud.neduet.edu.pk<br>Maryam Kharbey<br>kharbey4200429@cloud.neduet.edu.pk<br>Savera Khan<br>khan4203747@cloud.neduet.edu.pk |
| **8** | **Supervisor Name** (along with email address) | Maheen Mazhar<br>maheen@neduet.edu.pk |
| **9** | **Pictures (If any)** |  Stainless Steel Pieces  Carbon Conductive Ink |

Doctor Bldaing Using Scale



Dip Coating

Soldering

Preparaion of Supercapacitor Device

Three Electrodes EIS Setup