Designing a System to Generate Electricity from Usual Surrounding Motions through Piezoelectric to Run Surveillance Systems on the Port

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Declaration

It is hereby declared that

1. The Final Year Design Project (FYDP) submitted is my/our own original work while completing a degree at Brac University.
2. The Final Year Design Project (FYDP) does not contain material previously published or written by a third party, except where this is appropriately cited through full and accurate referencing.
3. The Final Year Design Project (FYDP) does not contain material which has been accepted, or submitted, for any other degree or diploma at a university or other institution.
4. I/We have acknowledged all main sources of help.

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Ethics Statement

The similarity index result of this report is 8%.

Abstract/ Executive Summary

The modern world has been urged to develop alternative methods of energy generation as a means of a solution due to the rise in energy demand and the depletion of non-renewable resources. The future will be secure if the shift to renewable energy sources for electricity consumption occurs efficiently and promptly. One of the renewable power generations the paper suggests is piezoelectric power generation using piezoelectric disks. Piezoelectric disks are such a device that converts mechanical energy into electrical energy. This paper presents an innovative approach to harnessing mechanical energy from our usual surrounding motion and converting it into electrical power for powering surveillance systems in ports. The piezo generates AC voltage. Subsequently, the AC voltage is transformed to DC voltage via a rectifier. After that the energy is stored in a battery, facilitating the conversion from DC to AC through an inverter to supply power to the surveillance system.

Acknowledgement

We would like to convey our gratitude to Dr. A.S. Nazmul Huda, who is our coordinator and an Associate Professor in the BRAC University Department of Electrical and Electronic Engineering. Our Final Year Design Project's success was significantly influenced by his guidance in problem-solving, data collection, system design, and managing the complexities of paperwork. We also like to sincerely thank Nahid Hossain Taz and Raihana Shams Islam Antara, Lecturer in the Department of Electrical and Electronic Engineering at BRAC University. Their advice, assistance, and mentorship were really helpful to us on our journey. The depth of Nahid Hossain Taz and Raihana Shams Islam Antara's knowledge and dedication to our progress was crucial in the accomplishment of our project. We worked together as a strong team to complete this task over the duration of a year. We were able to successfully complete our project because of the united commitment of Dr. A.S. Nazmul Huda, Nahid Hossain Taz, Raihana Shams Islam Antara, and our group members work of passion. We pay plenty of gratitude to everyone who helped, advised, and inspired us along our journey.

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Chapter 1: Introduction [CO1, CO2, CO10]

1.1 Introduction

Power generation is of paramount importance as it underpins modern life by providing electricity for our daily usage. We all know that the common practice is to generate electricity by using natural resources like coal, gas, oil, fossil fuel, nuclear power, hydropower, wind energy, and solar energy. Even with these many natural sources, it is hard to cope with the ever-increasing demand for electricity. Furthermore, the relentless consumption of non-renewable energy sources, such as fossil fuels, oil, coal, and gas, is driving us toward a precarious state of inadequacy. This concerning deficiency in non-renewable energy sources is looming on the horizon, prompting a pressing need to transition towards sustainable alternatives. The urgency to find sustainable energy sources has led to a significant shift towards renewable energy options. Renewable energy sources that are economically viable and environmentally sustainable are the way forward. Commonly utilized renewable energy sources for power generation include hydropower, wind energy, and solar energy, each contributing to reducing our reliance on fossil fuels.

However, amidst these well-established renewable sources, there exists a unique and promising avenue within the realm of renewable energy – piezoelectric energy generation. Piezoelectric power generation harnesses mechanical stress or vibrations to generate electricity. This innovative approach relies on piezoelectric discs that, when subjected to pressure or mechanical deformation, generate electrical voltage. The conversion of mechanical energy into electrical power through piezoelectric materials offers a compact, efficient, and sustainable means of electricity generation. It has the potential to contribute significantly to the diversification of our energy mix and mitigate the impending energy crisis.

For our design project, we have chosen to explore this unique and promising renewable energy source to generate power and provide support to the grid. The utilization of piezoelectric energy generation not only aligns with the global shift towards sustainability but also opens new possibilities for generating electricity from a wide range of sources, such as foot traffic, vibrations, and even ambient movements. As we delve deeper into the potential of piezoelectric power generation, we aim to contribute to the growing body of research in this field and help pave the way for a more sustainable and energy-secure future.

1.1.1 Problem Statement

The need for energy has been growing at an alarming rate in the current situation, and the availability of energy resources is not abundant for sustainable development. To compensate for the growing demands, it is imperative to develop an economic pollution-free inexhaustible energy resource. Coal, furnace oil, diesel, and natural gas will remain the main powerhouses in driving the world's economy for the foreseeable future. Fossil fuels are a finite resource as it takes 1 year to burn them while the duration of making them takes 15,000 years [1]. Furthermore, the generation of electricity using fossil fuels emits carbon dioxide (CO_2), a gas that produces smoke and causes global warming [2]. Consequently, the earth's temperature is increasing and the CO_2 creates an earth's thermal blanket which causes radiated heat from the earth to not pass into the atmosphere [3]. Moreover currently, due to rising import costs, the Bangladesh government recently suspended all diesel-powered power plant operations. The diesel-powered plants generate about 6% of Bangladesh's total electricity [4]. Following the COVID-19 pandemic in 2021, a large portion of the world experienced shortages and rising prices in oil, and gas which marked the beginning of the 2021–2022 global energy crisis. The crisis was brought on by several economic factors, including the quick post-pandemic economic recovery that exceeded the unavailability of energy, and it worsened after the Russian invasion of Ukraine in 2022, leading to a widespread worldwide energy crisis. Natural gas prices hit record highs, which had an impact on electricity prices in several markets. The price of oil reached its highest point since 2008 [5]. Due to all these alarming issues, there might be some disruption to meet the electricity demand. The sustainability and dependability of a country's electric power supply have a significant impact on its industrial and economic growth [6]. In light of the fact that several nations have already begun establishing renewable energy facilities for power generation [7], why should Bangladesh lag behind? To include Bangladesh in such a global transformation, we tried to give a little support on those issues.

Furthermore, a port is a great factor in the sustainable economic development of the country. Chittagong Port conducts more than 90% of Bangladesh's export-import activity. The port not only makes more than $30 billion per year, but it also contributes to the country's numerous development initiatives [8]. These ports are not only crucial hubs for trade and commerce but also intricate ecosystems where the seamless operation of surveillance systems is paramount. These surveillance systems play an indispensable role in ensuring the safety, security, and efficiency of port activities. However, it is worth noting that these systems are substantial consumers of electrical energy, drawing power from the national grid. Since the port operations are a round-the-clock affair, maintaining an uninterrupted power supply is imperative to keep these critical systems operational at all times. The continuous energy demands of ports and their surveillance systems can place considerable stress on the national grid, potentially resulting in disruptions and load shedding that affect the general populace.

The growing challenge of meeting escalating energy demands while simultaneously managing the depletion of traditional resources has prompted a search for alternative sources of power generation. Exploring innovative approaches like piezoelectric power generation not only aligns with sustainability goals but also offers the potential to alleviate the strain on the national grid, ensuring the seamless operation of essential infrastructure and promoting overall energy resilience.

1.1.2 Background Study

We examined and studied the current state of the whole world. The whole world is now going through a bad time due to the scarcity of natural resources. To solve this crucial problem our project could be an efficient solution.

In Bangladesh, the per capita power generation stands at approximately 426 kWh, while the per capita power consumption amounts to roughly 375 kWh [9]. To ensure that all of the country's residents have access to electricity, the government has plans to boost power generation. By 2030, it is intended to offer everyone access to modern, dependable, inexpensive energy. In accordance with Bangladesh's Renewable Energy Policy, a goal has been established to produce. By 2020, renewable energy will provide 2000 MWh, or 10% of all power [9]. Even so, The target could not be achieved for a number of reasons [9]. After realizing the gravity of this crucial problem we were adamant about solving this problem. We all know that the common practice is generating electricity using natural resources like coal, gas, nuclear power, hydropower, wind energy, and solar energy. Even with these many natural sources, it is hard to cope with the demand for electricity. So, we looked for studies and other research works to find a unique step toward the generation of electricity via a new methodology. To find a new methodology to generate electricity we searched for different types of renewable energy. The common renewable energy sources are solar energy and wind. Searching for new renewable energy we discovered piezoelectric material that can generate voltage and we all know that we can generate electricity where there is a difference in voltage. We found a lot of papers that worked on piezoelectric crystals. A lot of papers worked on generating electricity and they succeeded in generating electricity.

According to a paper, they apply this in their busy road, which is applied in the upper layer of the road. After the trial, they see that a 5-ton weighted vehicle can generate 2000 volts. A 1 KM cluster of such a generator can generate 400 kWh of energy. If 600 vehicles are allowed to go through this road for an hour, it can power up to 600-800 hours [10]. In 2008, a piezoelectric system was installed in Tokyo by the East Japan Railway Company. A piezoelectric floor was installed in Tokyo Station to use energy from footsteps to power ticket gates [11]. A research paper on Electrical Power generation by footstep using a Piezo-electric found an output voltage of about 10-15V from their model [12]. In one example of Piezoelectric oceanic wave energy converters (OWECs), a harvester measuring 180 meters and weighing 1350 tons was able to achieve an output power of approximately 750 kW [13].

After reviewing those papers and data we also gave a thought to work with the piezoelectric material and harness energy. This will also have a good impact on the power sector of our nation.

1.1.3 Literature Gap

After reviewing those papers and data, we found that they used the system in those places where the output would be on a good scale. Yet they did not give thought to using those powers wisely for the betterment of the nation's power sector. In our project, we will generate electricity through piezoelectric material and will run the surveillance system. At the same time, we will also store and generate electricity in a battery for future usage. As well as we will also have a connection from the grid for emergency purposes or when the source for piezoelectric material is unavailable.

1.1.4 Relevance to current and future Industry

The Global Piezoelectric Materials market is expected to grow at a rapid pace between 2023 and 2029. The market is predicted to increase during the anticipated period because key players are adopting strategies at an increasing rate in 2023. Due to the COVID-19 pandemic, the global market for piezoelectric materials is expected to be worth USD 1265.9 million in 2022 and rise to USD 2085 million by 2029, growing at a CAGR of 7.3% from 2023 to 2029 [14]. So, we can say that the use of piezoelectric material is increasing on a good scale which exhibits that students or researchers will be more enthusiastic to work with piezo and generate electricity.

The system that we want to design can be used not only in ports but also in many other places where a lot of motions are created by humans or nature. This system can be implemented in many places. The future scopes of our designed system are as follows:

- City Roads: On city roads, there are a lot of speed breakers and a lot of vehicle moves. So, a lot of pressures are formed by the vehicles, and from this pressure, electricity can be generated through the piezoelectric. With this generated electricity the street lights and the close circuit (CC) cameras can be powered up.
- Footpaths: Bangladesh is one of the most populated countries. So many pedestrians use footpaths to reach their destinations. If we implement our system under the pavement, it will be able to generate electricity from the walking pressure of pedestrians. With this generated electricity the street lights and the close circuit (CC) cameras can be powered up.
- Railway Tracks: Railway tracks are one of the important places which are responsible for the generation of large energy as a huge amount of pressure is exerted by trains on the railway tracks. The embedded piezoelectric crystals at the railway tracks where wheels make contact with the tracks and these materials get excessive pressure and force, and because of this greater amount of energy can be stored.
- Airport Runway: A large amount of pressure is exerted on runways when the aircraft takes off or lands. If we place the piezoelectric clusters here then we can convert this mechanical energy. The efficiency of the system can be improved by placing the stacked structure which consists of several layers of piezoelectric clusters and have the capacity to handle a huge amount of pressure.
- Shopping Malls: Here also we can implement a system like footpaths. A lot of people walk in the mall and from that walking pressure electricity can be generated. With this generated electricity the surveillance system of the malls can be powered up.
- University: Students frequently move from here to there in the university. Especially at the entrance gate of the premises. So if we implement our system at the entrance gate then we can generate a large amount of electricity. This generated electricity can be used to power the university's surveillance system.

- Wind Mills: In windmills when the blades rotate a good amount of vibrations are formed in the blades. So, if we can place a cantilever beam in the blades it can generate electricity.

1.2 Objectives, Requirements, Specification, and Constraint

Every design must adhere to certain guidelines and standards in order to be as faultless as possible, but as no design is ever perfect, every design, regardless of how efficient and successful it is, also has some limitations. Here, we've included every requirement, specification, and constraint that applies to our designs.

1.2.1. Objectives

As the world is modernizing, the consumption of electricity is also increasing rapidly. There are a lot of ways to generate electricity from natural resources but currently, those are not enough to generate enough electricity. Even electricity generation through renewable resources cannot meet the demand. Moreover, A lot of the motions around us are created by humans or nature. These motions are of no use. So, what if we use these motions in a creative way for our betterment? Furthermore, the surveillance system of the port consumes a good amount of electricity and this electricity is supplied by the national grid. That is why considering all this the objectives of our designs are:

1. Designing a system to generate power through piezoelectric using surrounding motions.
2. To provide some support to electricity demand.
3. Individualization of surveillance systems at ports

1.2.2 Requirements

Functional Requirements:

- Cost: The price-to-utility ratio for electricity produced must be kept at a minimum i.e. per unit cost of electricity should be less compared to the cost of setting up the unit system. The material should be compatible with the desired fabrication method and cost-effective to produce.
- Minimum Power: The system should generate enough power to run at least the surveillance system. Generally, a CCTV camera consumes about 2 watts to 15 watts of power [15]. There are about 520 CCTV cameras in the Chittagong port [16]. Moreover, the monitoring system includes computers and lights. So, overall a port consumes a minimum of 15kW. That's why we have generated a minimum of 15kW through our design system.

- Functionality: As there will be a lot of sub-systems, it must be a controlled system. In the context of software development, functionality refers to the tasks that the software is intended to perform, such as processing data and providing user interfaces. For physical products, functionality can refer to the specific actions or abilities that the product is designed to provide, such as the ability of a piezoelectric material to generate an electric charge in response to mechanical pressure. Functional requirements are a critical part of the product design process, as they define the specific capabilities and features that the product must possess in order to meet user needs and expectations
- Disruption: As the port is a busy area, our system should not be a problem for the port. The potential disruption of piezoelectric materials in a port area is a critical functional requirement that must be addressed during the design and manufacturing process. Piezoelectric materials used in port areas are exposed to a variety of environmental stresses, such as humidity, temperature variations, and saltwater corrosion, which can cause disruption and degradation of the material's functionality. The material must be designed to withstand these harsh conditions and maintain its piezoelectric properties, as it is essential for monitoring and controlling various port activities. In addition, the material must be able to withstand mechanical stresses and shocks caused by shipping traffic, cranes, and other equipment in the port area. Proper Handling, testing, and maintenance can help minimize the risk of disruption and ensure the longevity and reliability of the piezoelectric material in the port area. These functional requirements must be carefully considered to ensure that the material will function effectively in the demanding port environment.
- Inverter and Rectifier: These are very essential to keep the AC or DC according to the device. Inverters and rectifiers are critical functional requirements for the use of piezoelectric materials in port areas. Inverters are used to convert the direct current (DC) produced by piezoelectric materials into alternating current (AC) that can be used to power electrical devices in the port area. Rectifiers, on the other hand, are used to convert the AC power from the electrical grid into DC power that can be used to charge the piezoelectric materials. The inverters and rectifiers must be designed to operate reliably in the harsh port environment and must be able to withstand fluctuations in voltage and frequency. They must also be able to operate efficiently to ensure that the energy generated by the piezoelectric materials is used effectively. Proper design, installation, and maintenance of the inverters and rectifiers are critical to ensure the effective operation of the piezoelectric materials in the demanding port environment.
- Charging Circuit: As the battery is needed to charge by the stable voltage that's why charging circuit is a must. Piezoelectric materials produce direct current (DC) that must be converted into usable electrical power to charge batteries or power electronic devices. The charging circuit must be designed to operate reliably in the harsh port environment and must be able to handle the fluctuating current and voltage produced by the piezoelectric materials. It must also be able to regulate the charging voltage and current to prevent damage to the batteries or electronic devices. Proper design, installation, and maintenance of the charging circuit are critical to ensure the effective

operation of the piezoelectric materials in the demanding port environment. The charging circuit must also be designed to be efficient to ensure that the energy produced by the piezoelectric materials is used effectively.

Non-Functional Requirements:

- Surface: The surface required to implement the system would not be a master to implement this system. The surface of piezoelectric materials in port areas is an important non-functional requirement that must be considered during the design and manufacturing process. The surface of the material must be smooth and free of defects to prevent the accumulation of debris and other contaminants, which can interfere with the material's performance and accuracy. In addition, the surface of the material must be resistant to corrosion and erosion caused by exposure to saltwater and other harsh environmental conditions. The material should also be easy to clean and maintain to ensure that its surface remains free of debris and contaminants. These non-functional requirements are critical to ensuring that the piezoelectric material will provide reliable and accurate measurements in the demanding port environment.
- Monitoring Display: Monitoring is required just to see the values of a generation. So, it won't affect the system if it is not installed. The display must be designed to provide accurate and reliable data on the pressure levels and other relevant parameters, such as temperature and humidity. The display must be clear, visible, and easy to read, even in bright sunlight or low light conditions. It must also be designed to withstand the harsh environmental conditions in the port area, including exposure to saltwater, extreme temperatures, and high humidity. The display must be intuitive and user-friendly, allowing port personnel to quickly and easily interpret the data and make informed decisions based on the information provided. Proper design, installation, and maintenance of the monitoring display are critical to ensure the effective operation of the piezoelectric materials in the demanding port environment.
- Thermal Camera: A thermal camera can be used if we want to see the temperature of the piezoelectric disk. Since the disk will get a continuous pressure it might increase the temperature of those disks. The camera has the ability to identify hotspots and temperature anomalies swiftly and accurately. Thermal cameras are crucial for enhancing safety, optimizing operations, and ensuring the well-being of both equipment and individuals in diverse environments. Their versatility and reliability make them an indispensable tool in modern temperature monitoring and control systems.

1.2.3 Specifications

Table 1.1: Component level specifications of our designed prototype

Components Name	**Details**	**Purpose**
Piezoelectric	All the discs are made from selected copper, ensuring excellent conductivity and long-lasting use.	May apply mechanical force to create electric energy
Wind turbines	Each turbine will have 80mm(x3) Cantilever beams that generate +-48 volts. So with 5 sets of systems, we can generate 240 volts considering a wind speed of 5m/s	Core system that generates electricity
Inverters	● Maximum Supply Voltage:5.25V ● Maximum Operating Temperature: 70°C	Converting DC to AC
Rectifiers	● Peak Repetitive Reverse Voltage:40V ● Working Peak Reverse Voltage:40V ● DC Blocking Voltage:40V ● Average Rectified Output Current:1A	Converting AC to DC
Batteries	● Specific energy 35-40 Wh/kg ● Nominal cell voltage 2.1V ● Charge temperature interval Min. −35°C, max. 45°C	For storing the current
Charging circuit	● Input Voltage: DC 6-60V (max 80V) ● Control Precision:0.1V ● Output Type: direct output ● Voltage Tolerance: +/-0.1V	To stable the voltage
Piezo element 35MM	● The input voltage: 30vp-p max ● Ultra-thin and lightweight ● Low power consumption for voltage type ● Operating Temperature: -20~70	Energy harvest from have motion along with the device
Piezoelectric disks	● A piezo-ceramic with coated electrodes ● Piezo material: PIC255 ● Outer diameter: 8 mm ● Thickness 2 mm	By using oppositely poled pairs of piezoelectric disks, the transducer's components are kept to a minimum when operating at high voltage.
Voltage Stabilizer	● Three-phase four-wire 300-460V input voltage, ● Output voltage: three-phase four-wire 380V ● Adjustable accuracy of output voltage: 2-5%, ● Power class more than 50 KVA, Response speed ≤1.5S ● Auto or manual start option ● Insulation resistance ≥2MΩ	Even throughout voltage fluctuations, a voltage stabilizer is supposed to supply a constant voltage to a load.

1.2.4 Technical & Non-technical Consideration and Constraints in the design process

Technical Consideration/Constraints:

- Unstable voltage: When a different amount of pressure is applied to the piezoelectric, it produces unstable voltage. Unstable voltage can cause equipment failure, which can result in costly downtime, repairs, and replacements. We know that unstable voltage is not good for battery health. For this reason, the battery will not provide the expected service. Unstable voltage can create safety hazards, such as electrical shock and fire, which can endanger workers and damage equipment.
- Power loss: There might be some amount of power loss due to copper loss in the transmission line between the source and load. The power output of piezoelectric materials is generally low, which limits their usefulness for generating large amounts of electricity.
- Battery: Battery health decreases after a certain period. Battery constraint refers to the limitations or restrictions imposed by the available battery capacity or energy storage capacity on a device or system. This constraint can impact the performance, functionality, and operation of the device or system, especially if the battery capacity is insufficient for the intended purpose or usage.
- Installation constraints: Piezoelectric materials need to be installed in a way that maximizes their sensitivity to mechanical stress. In a port area, where there may be limited space and access, this can be a constraint. It may be necessary to design custom mounting solutions or use alternative materials to achieve the desired performance.

Non-technical Consideration/Constraints:

- Natural Calamities: The installed device could be hampered during disasters like tropical storms, tsunamis, storm surges, blooms of toxic algae, etc. The sensors themselves have limitations in terms of their sensitivity and accuracy. They may not be able to detect small or subtle vibrations, or they may be affected by environmental factors such as temperature and humidity. Regular maintenance and calibration are required to ensure their continued effectiveness.
- Repairing: After 10 years, the piezoelectric material needs to be repaired. Piezoelectric materials are commonly used in various applications such as sensors, actuators, and energy harvesting devices. If a piezoelectric material is damaged, it may not function properly, and repairing it may be necessary. If the damage is severe or the piezoelectric material cannot be repaired using an adhesive, it may be necessary to replace the damaged part. In this case, the damaged part should be removed carefully and a new piece of piezoelectric material should be installed. It is important to ensure that the replacement material has the same properties as the original material to avoid affecting the device's overall performance.

- Components Reliability: Since in ports electricity is required continuously that's why the reliability of the components may get hampered.
- Wind flow: The direction of the wind is also vital for our turbines, where bi-directional turbines are almost impossible to implement since rotating turbines in only one direction are more effective. However, the wind direction is constantly changing in large open areas like ports.
- Temperature sensitivity: Piezoelectric materials are highly temperature-sensitive, which means that their performance can be affected by changes in temperature. In a port area, where temperatures can vary widely depending on the time of day and weather conditions, this can be a significant constraint.
- Maintenance and durability: Piezoelectric materials can be fragile and require careful handling and maintenance to ensure their continued performance. In a port area, where equipment is subject to harsh conditions and frequent use, it is important to choose materials that are durable and easy to maintain.

1.2.5 Applicable compliance, standards, and codes

Table 1.2: Applicable standards and codes for required different devices for the system

Device/ Technology	Standard Code	Standard Name	Standard Details
Piezoelectric	IEEE177-1966	Standard Definitions and Methods of Measurements for Piezoelectric Vibrators	The equivalent electric circuit of a piezoelectric vibrator and its parameters are reviewed. The determination of these parameters by the transmission method is described. The method is suitable for frequencies up to about 30 MHz for the commonly encountered ranges of the capacitance ratio r and the figure of merit M provided that errors due to instrumentation are taken into account. The equations presented in this standard have been formulated to correct these errors.
	ANSI/IEEE176-1978	IEEE Standard On piezoelectricity	This standard on piezoelectricity contains many equations based upon the analysis of vibrations in piezoelectric materials having simple geometrical shapes. Mechanical and electrical dissipation is never introduced into the theoretical treatment, and except for a brief discussion of nonlinear effects in Section 5, all the results are based on linear piezoelectricity in which the elastic, piezoelectric, and dielectric coefficients are treated as constants independent of the magnitude and frequency of applied mechanical stresses and electric fields.

Battery	IEEE 1653.2-2020	IEEE Standard for Uncontrolled Traction Power Rectifiers for Substation Applications up to 1500 V DC Nominal Output	The design, manufacturing, and testing unique to the application of uncontrolled semiconductor power rectifiers for direct current (DC) supplied transportation substation applications up to 1500 V dc nominal output is covered in this standard. The standard is intended to address traction power substation rectifiers that are to be provided as part of a rectifier transformer unit or that are to be provided separately. Application information and extensive definitions of related technical terms are included.
Rectifier	IEEE 1653.2-2020	IEEE Standard for Uncontrolled Traction Power Rectifiers for Substation Applications up to 1500 V DC Nominal Output	The design, manufacturing, and testing unique to the application of uncontrolled semiconductor power rectifiers for direct current (DC) supplied transportation substation applications up to 1500 V dc nominal output is covered in this standard. The standard is intended to address traction power substation rectifiers that are to be provided as part of a rectifier transformer unit or that are to be provided separately. Application information and extensive definitions of related technical terms are included.
Inverter	IEEE 2800-2022	IEEE Standard for Interconnection and Interoperability of Inverter-Based Resources (IBRs) Interconnecting with Associated Transmission Electric Power Systems	Uniform technical minimum requirements for the interconnection, capability, and lifetime performance of inverter-based resources interconnecting with transmission and sub-transmission systems are established in this standard. Included in this standard are performance requirements for reliable integration of inverter-based resources into the bulk power system, including, but not limited to, voltage and frequency ride-through, active power control, reactive power control, dynamic active power support under abnormal frequency conditions, dynamic voltage support under abnormal voltage conditions, power quality, negative sequence current injection, and system protection. This standard also applies to isolated inverter-based resources that are interconnected to an ac transmission system via dedicated voltage source converter high-voltage direct current (VSC-HVDC) transmission facilities; in these cases, the standard applies to the combination of the isolated IBRs and the VSC-HVDC facility, and not to an isolated inverter-based resource (IBR) on its own.

1.3 Systematic Overview/summary of the proposed project

This project presents an innovative approach to harnessing mechanical energy and converting it into electrical power for powering surveillance systems in ports. The proposed system uses the piezoelectric effect to generate AC voltage when pressure is applied to a piezoelectric device. Subsequently, the generated AC voltage is rectified to DC voltage using a rectifier circuit. Furthermore, a DC-DC buck converter is integrated into the system to step down the voltage and efficiently store the harvested energy in a rechargeable battery, allowing for continuous operation even when external pressure sources are intermittent. In the final stage of the system, an inverter is utilized to convert the stored DC voltage back into AC, enabling the power supply of the surveillance system. This approach not only ensures a consistent and uninterrupted power source but also promotes sustainability by utilizing renewable mechanical energy sources.

This project's results demonstrate the feasibility and effectiveness of energy harvesting using piezoelectric devices, providing a sustainable and self-sufficient power solution for surveillance systems in challenging environments where conventional power sources may be limited or unavailable.

1.4 Conclusion

It is impossible to overestimate the importance of electricity generation in contemporary life. The constraints of finite resources have been made clear by our reliance on conventional non-renewable sources of electricity. The need to switch to sustainable alternatives has become more critical as the demand for energy keeps rising. A considerable movement toward renewable energy solutions has occurred as a result of the pressing need to discover sustainable energy sources. In terms of renewable energy, piezoelectric energy generation is a distinctive and promising option. Our focus on sustainability and resilience is reflected in our determination to fully utilize piezoelectric power generation in our design project. By embracing this revolutionary technology, we hope to not only add to the body of knowledge but also open the door for a future of energy that is more safe and sustainable. Through such initiatives, we can tackle the most important problems of our day and create a world where clean and renewable energy sources will dominate the energy sector.

Chapter 2: Project Design Approach [CO5, CO6]

2.1 Introduction

We are at an intersection in the development of green energy as we look for new and sustainable ways to meet the constantly increasing need for energy. This chapter of our paper gives a clear idea about the complexities of our project's designs, which are set to unlock the unused potential of piezoelectric materials in the production of power. We are looking for alternatives to the typical production of electricity methods that rely on fossil fuels and other limited resources as we stand on one side of an anticipated energy disaster. Although traditional methods are necessary, they come with limitations in terms of availability and environmental impact. By 2050, it's anticipated that renewable energy sources will account for 62% of all energy produced. whereas Slovakia's whole production capacity of renewable energy in 2019 was only 13% of the total quantity produced globally (27%) [17]. So, We look into cutting-edge power generation techniques because of the urgent need for an energy revolution.

The modern and exciting idea of piezoelectric energy generation is at the root of our study. Piezoelectric materials have a remarkable capacity to transform pressure, vibration, or mechanical stress into electrical voltage [18]. The basis of our project is this transformational idea, which provides a compact, productive, and sustainable way to generate electricity. Piezoelectric material's unique properties make them the ideal choice for tapping into a multitude of energy sources. Even though other renewable energy sources like solar, wind, and hydropower are important parts of our energy mix, they frequently depend on particular environmental factors or demand expensive infrastructure. In contrast, piezoelectric energy production utilizes the diversity of its sources, which range from people's footsteps in cities to ocean waves nearby to port operations.

This chapter begins with an in-depth discussion of our three unique design approaches, each of which is an illustration of the flexibility and potential of piezoelectric power generation. These methods range from utilizing pressure applied to piezoelectric crystals, employing wind turbines to deflect polyurea-coated cantilevers, to harnessing the kinetic energy of ocean waves using specialized converters. Our comprehensive review, supported by in-depth block diagrams and process breakdowns, reveals the complex inner workings of these strategies. The ultimate goal is to create a more sustainable, diverse, and secure energy environment rather than only providing power.

2.2 Identify multiple design approaches

In order to choose the optimal design approach for our project from the three design approaches, we have chosen a few criteria. Finding the offered design that best matched our objectives, requirements, and specifications was our key objective in this circumstance.

2.2.1 Approach 1: Generating Electricity through piezo-electric crystal by Pressure

A piezoelectric material produces an electric charge on its surface when mechanical stress is applied or when deformation occurs due to an external force. This phenomenon is called the direct piezoelectric effect. Conversely, the phenomenon in which a piezoelectric material experiences mechanical deformation or strain when subjected to an applied electric field is called the indirect piezoelectric effect. The generation of electrical energy from mechanical energy is illustrated in the following figure.

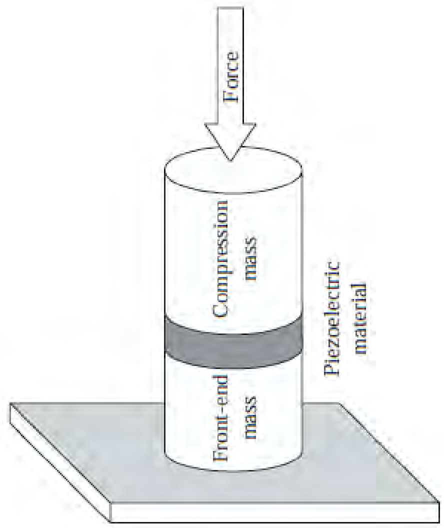


Figure 2.1: Mechanical Configuration of the piezoelectric generator [19]

Implementing the method for generating electricity by applying pressure on piezoelectric crystals is an approach with a variety of applications. In practical applications, this idea can be used in a variety of ways to gather mechanical energy and transform it into electrical energy. For instance, piezoelectric components can be incorporated into existing infrastructure, such as brakes or roads, to harvest energy from the force of passing automobiles. This strategy works perfectly with our main goal, which is to construct a system at the port's entry that not only generates electricity but also helps to lower grid pressure.

We have decided to emphasize the integration of piezoelectric components within the speed breaker of the port's entrance in our particular solution. The mechanical pressure that passing vehicles apply to the speed breaker causes it to become activated, which causes the piezoelectric crystals to start generating electricity. With the surveillance system as the primary target, this energy will be efficiently stored and then used to power numerous equipment and systems. We hope to accomplish this by promoting sustainability and reducing the demand for traditional energy sources. We anticipate a more eco-friendly and energy-efficient port entrance that demonstrates the revolutionary potential of pressure-driven piezoelectric crystals in contemporary engineering solutions. The process of generation is given below through a flow chart,

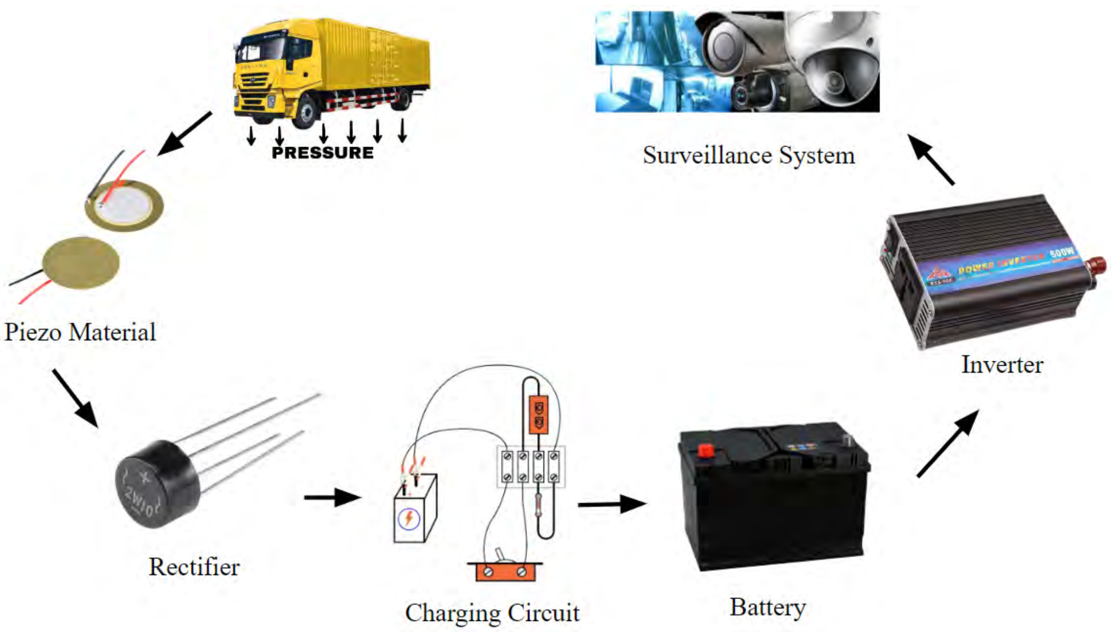


Figure 2.2: Flow of Generating Electricity through piezo-electric crystal by Pressure

2.2.2 Approach 2: Generating Electricity using the deflection of the polyurea-coated cantilever by the turbine

Our second approach focuses on capturing wind energy by attaching cantilever beams to wind turbines inside of specially made housings. This strategy makes use of the dynamic interaction between the cantilever beams and wind turbine blades. The cantilever beams are in touch with the turbine blades as they rotate in reaction to wind flow, which deflects the blades. Due to the distinct piezoelectric properties of polyurea sheets, this deflection initiates a process that generates electricity. A miniature design for the concept [20] is given below,

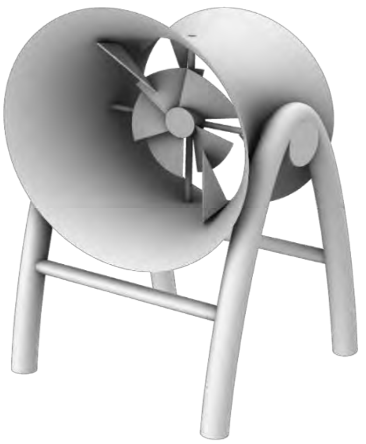


Figure 2.3: A miniature design for the concept

When mechanical stress is applied, a material used in our method called polyurea films has a unique ability to display the piezoelectric effect. These polyurea-coated cantilever beams generate electrical energy when wind turbine blades impact them, causing potential differences inside the material. This novel idea makes use of the plentiful and natural wind resources that are frequently present close to port regions. Ports usually face major wind patterns because of their open, big location near the sea. By implementing windmill-like systems, such as the one shown in the provided illustration, we hope to harvest this wind energy. These devices may adjust to the port's particular environmental circumstances, optimizing the amount of electrical energy generated. The process's functional flow provided below,

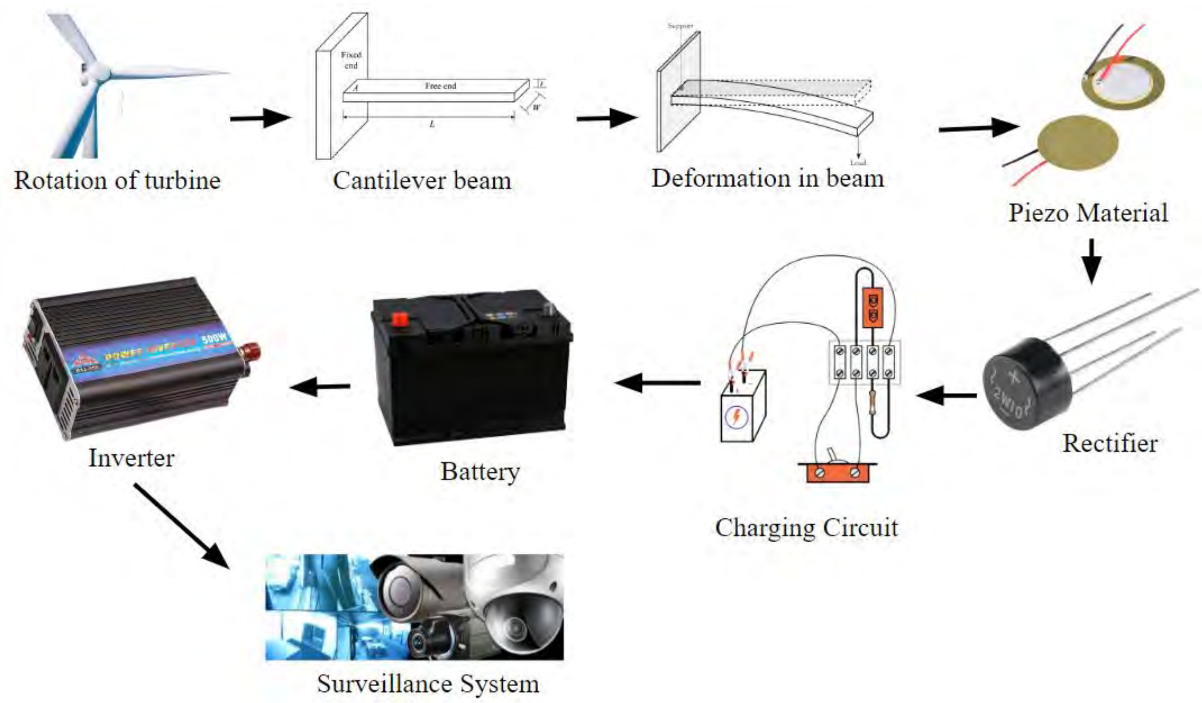


Figure 2.4: Flow of Generating Electricity using the deflection of the polyurea-coated cantilever

We enhance the security and dependability of port operations while simultaneously promoting environmental sustainability by developing self-sufficient energy systems within ports.

2.2.3 Approach 3: Power Generation by Piezoelectric Oceanic Wave Energy Converters (OWECs)

The third approach introduces the use of piezoelectric oceanic wave energy converters (OWECs), a technique for harnessing clean, renewable energy from the vast kinetic potential of ocean waves. By directly converting the oscillating motion of ocean waves into electrical energy using piezoelectric materials, these modern devices open up a promising new path for the creation of sustainable power. To capture the kinetic energy of ocean waves, they use mechanically powered, semi-submerged generators. The use of piezoelectric transducers defines OWECs from other devices. These transducers are positioned inside the apparatus and react to the pressure from the waves. A pendulum inside the cylinder forces the generator to rotate as it oscillates in response to the waves, which are attached to the seafloor by a flexible chord. By rotating the piezoelectric strips, the kinetic energy of the wave motion is successfully transformed into electrical voltage through the piezoelectric disks. The inherent transduction properties are displayed by the piezoelectric crystal's structural structure, such as a crystal film, which is connected to single crystals. The degree of deformation freedom determines the efficiency of piezoelectric energy harvesters, which in turn affects the coefficient of piezoelectric materials. The electrostatic, electromagnetic, or piezoelectric qualities provide the foundation for the majority of oceanic wave energy conversion systems [21].

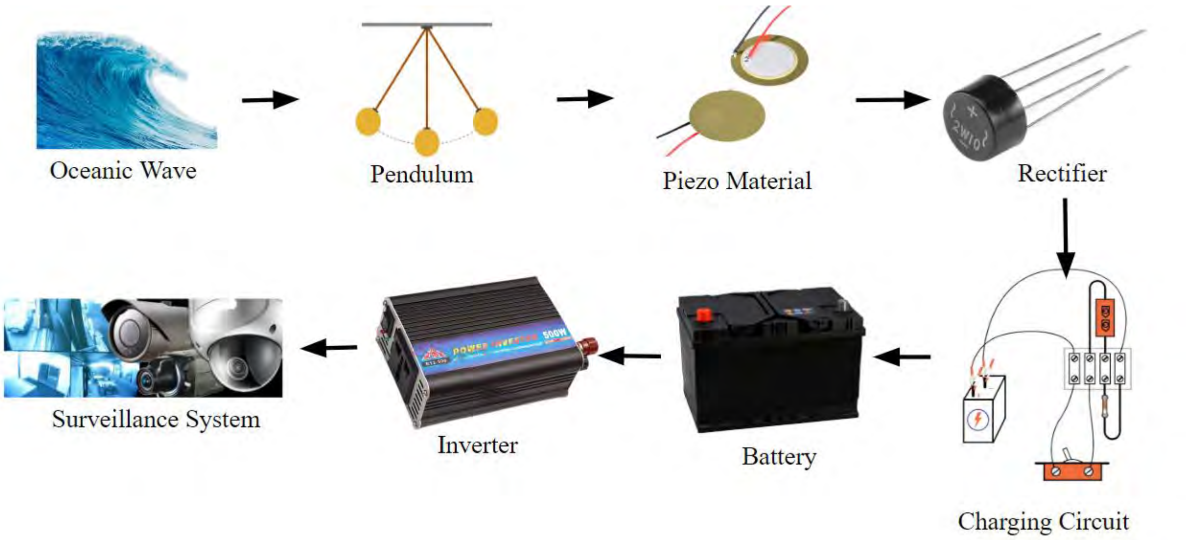


Figure 2.5: Flow of the Generation of Electricity by an Oceanic Wave Energy Converter.

Compared to previous ocean wave energy collecting systems, OWECs offer a number of benefits. They are highly effective and environmentally friendly because they are small, light, and do not need intermediary devices. Additionally, OWECs contribute to the development of sustainable and intelligent cities for the future by having negligible negative effects on the ocean environment. This approach offers self-powered surveillance, a cleaner environment, and enormous potential for economic growth due to effective resource management.

2.3 Describe multiple design approach

2.3.1 Approach 1: Generating Electricity through piezo-electric crystal by Pressure

A number of crucial procedures must be followed in order to generate electricity using piezoelectric crystals and transform it into a form that can be used to operate the monitoring system at the port entry. We will implement this design beneath the speed breakers of the entrance of the ports. A flow chart is given below to illustrate the process,

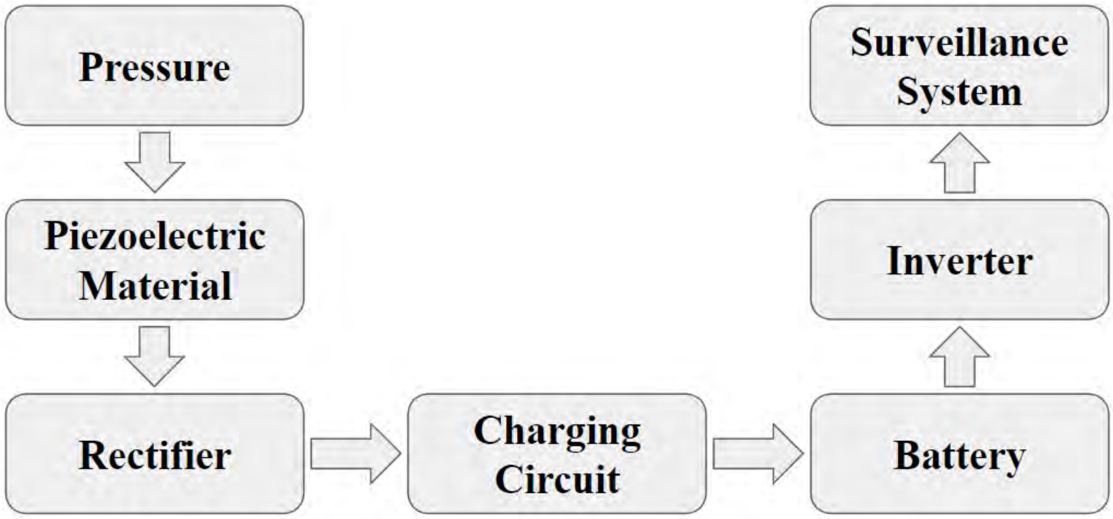


Figure 2.6: Block Diagram of Generating Electricity through piezo-electric crystal by Pressure

- Piezoelectric Material Activation: When any vehicle passes over a speed breaker it creates a good amount of pressure on the speed breaker. The piezoelectric material activates or generates electricity when mechanical pressure or stress is applied to the disk. So, when a vehicle passes over a speed breaker it will activate the piezoelectric material. The piezoelectric material responds to pressure and produces alternating current (AC) voltage.
- Rectification: In order to efficiently store the electricity in a battery, the generated AC voltage must be changed into direct current (DC). A rectifier is used to make this happen. The rectifier converts the AC voltage into a steady DC current, guaranteeing that the energy is stored in a way that can be used to recharge the battery.
- Charging Circuit: The rectifier's DC current after that enters the charging circuit. Before the current enters the battery, the charging circuit's main function is to stabilize it. Maintaining the battery's health and lifetime requires a stable current. The performance of the battery might quickly deteriorate as a result of an inconsistent or unstable current, which is unsuitable for the overall system reliability.
- Battery: The battery is used to store the stable DC current. In this case, the battery serves as an energy storage device, preserving the generated electricity for use later on. Even when the pressure of the speed breaker is not being applied, the battery is essential for maintaining a constant power supply to the surveillance system.
- Inversion to AC: The battery-stored DC current is transformed back into AC when the surveillance system requires electricity. An inverter is used to do this process. The

inverter ensures that the electricity provided to the surveillance system is in the right form for functioning.

- Powering the Surveillance System: The surveillance system at the port entry can be powered by the inverter's AC output. The appropriate electrical power is supplied to the surveillance equipment, allowing it to monitor and secure the port efficiently.

This process of changing mechanical pressure into a useful electrical form is an example of an environmentally responsible way to use piezoelectric technology for energy harvesting.

2.3.2 Approach 2: Generating Electricity using the deflection of the polyurea-coated cantilever by the turbine

Our system can be developed into a hybrid model, where it will be integrated into a wind turbine. In such applications, we will be generating electricity from wind energy as well as from the vibration of piezoelectric material that will be coated to cantilever beams. Here, the cantilever beams will be much larger. Although the system will generate electricity, future studies will confirm how reliable the design is.

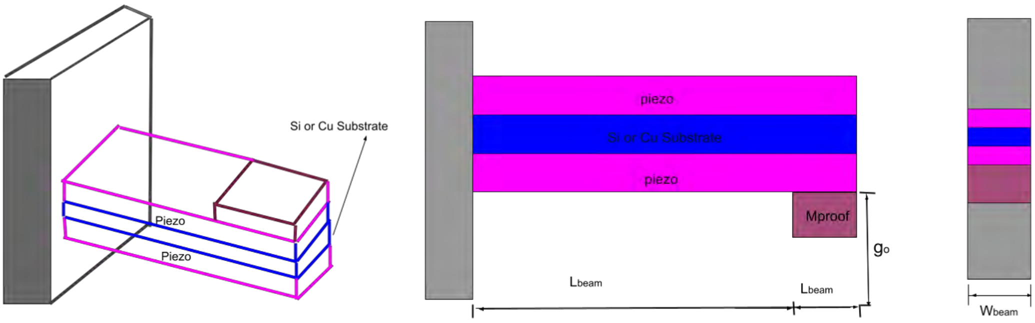


Figure 2.7: Detailed of a cantilever beam

Also an approximate diagram of how our beams will deflect when hit by windy turbine blades is

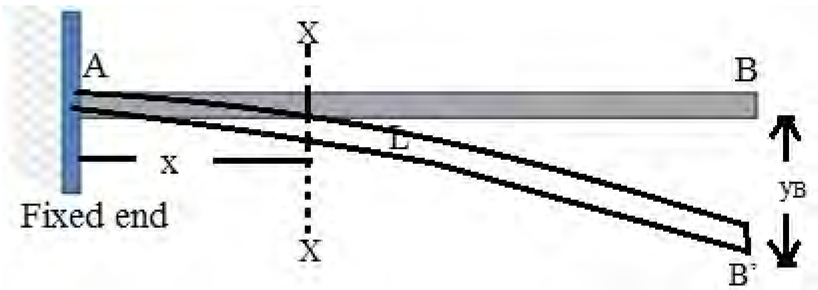


Figure 2.8: Cantilever Beam [22]

The lever shown above represents an approximate motion of how it will be deflected when the turbine blade moves and creates wind pressure. The whole process is illustrated in a block diagram given below,

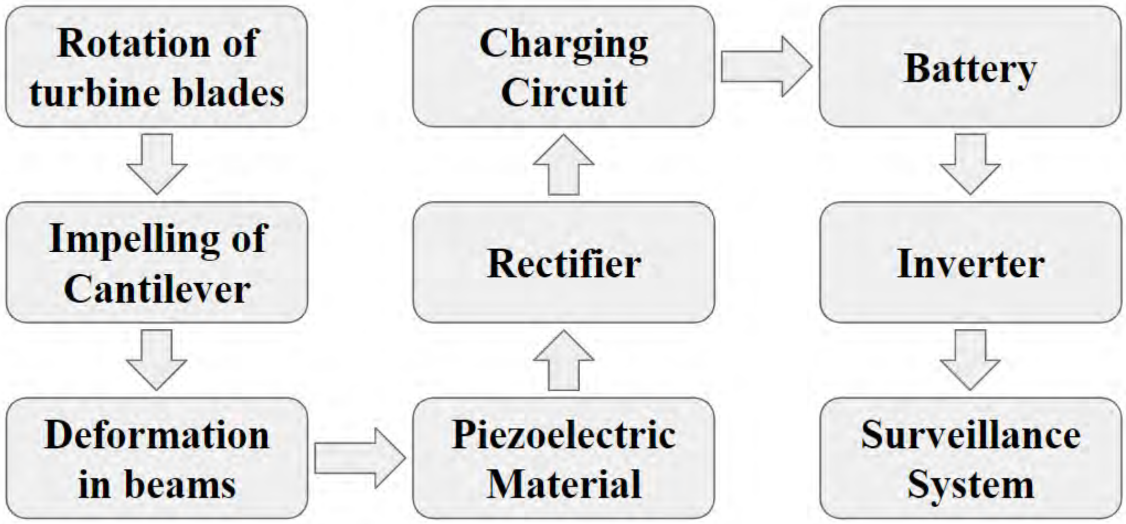


Figure 2.9: Block diagram of a piezoelectric thin sheet to produce electricity

The rotation of the turbine blades in response to the prevailing wind flow is the first step in this process. These blades rotate and come into contact with cantilever beams that have been placed precisely and are kept in particular enclosures. The cantilever beams are deflected as a result of this interaction. Polyurea films, which are renowned for their piezoelectric capabilities, are used to coat the cantilever beams. The piezoelectric material is excited by the distortion of these beams caused by the impact of the turbine blades, creating a potential difference within the material. An alternating current (AC) is produced as a result of this potential difference. The generated AC voltage is rectified to DC, assuring stability, before being stored in a battery. The monitoring system is then powered by the stored energy, which has been converted back to AC using an inverter to power up the surveillance system.

2.3.3 Approach 3: Power Generation by Piezoelectric Oceanic Wave Energy Converters (OWECs)

Piezoelectric Oceanic Wave Energy Converters (OWECs) are an environmentally friendly method for harnessing the kinetic energy of ocean waves. The block diagram of this approach is shown below:

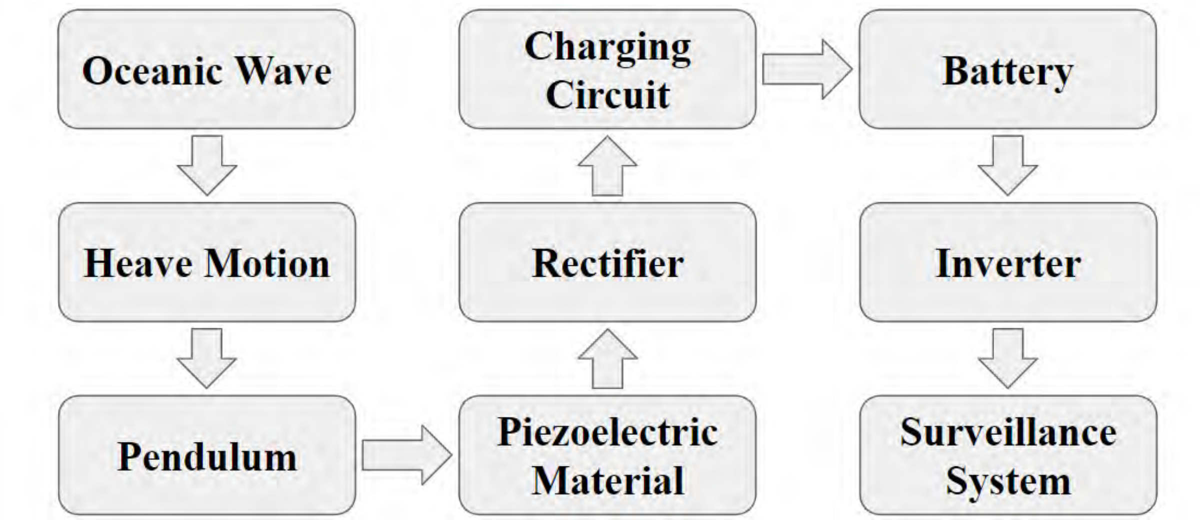


Figure 2.10: Block Diagram of the Generation of Electricity by Oceanic Wave Energy Converter.

- Oceanic Wave Motion: The motion of the waves in the ocean starts the process. The motion of the water becomes dynamic and sweeping as waves travel through the ocean.
- Pendulum Activation: The OWEC's built-in pendulum mechanism is powered by this oscillating motion. A vital component of the energy conversion process is played by the pendulum, which is made to oscillate in response to the motion of the waves.
- Impact on Piezoelectric Materials: The pendulum impacts a piezoelectric material assembly inside the OWEC as it oscillates. These piezoelectric materials experience mechanical stress as a result of the pendulum's impact, resulting in a piezoelectric effect.
- AC Voltage Generation: Alternating current (AC) voltage is created as a result of the piezoelectric materials' reaction to this mechanical stress. The piezoelectric effect, where the crystalline structure of the material generates electrical potential in response to mechanical deformation, is directly responsible for this AC voltage.
- Rectification: A rectifier is used for converting the generated AC voltage into a usable form for energy storage and use. To ensure a steady and regular flow of power, the rectifier converts alternating current (AC) into direct current (DC).
- Charging Circuit: After the DC current has been stabilized, it enters a charging circuit. Before the current enters the battery, this circuit's primary function is to control and stabilize it. The health and performance of the battery depend on a stable current.
- Battery: A battery is used to store the controlled DC current. The battery functions as an energy storage device, allowing electricity to build up during times of high wave activity as well as offering a constant power source during periods of low or no wave activity.

- Inversion to AC: When the surveillance system requires power, an inverter converts the battery's stored DC electricity back into AC. Inverters are essential for converting direct current (DC) into the AC power required by electrical equipment.
- Powering the Surveillance System: In order to provide a consistent and dependable source of electricity for security and monitoring reasons, the inverter's AC output is then directed to power the surveillance system.

The ability of OWECs to sustainably and safely harness the kinetic energy of ocean waves and turn it into electrical power is shown by this advanced operation. It highlights the possibility of eco-friendly energy options that can considerably improve port operations.

2.4 Analysis of Multiple Design Approach

We provide an in-depth analysis of each design approach in the table below, evaluating it according to a number of criteria. This analysis helps us to determine whether the three approaches to using piezoelectric energy for power generation are appropriate and effective.

Table 2.1: Analysis of design approaches based on criteria

Criteria	Design 1	Design 2	Design 3
Energy Efficiency	High efficiency due to direct pressure on piezoelectric crystals.	Moderate efficiency as wind energy is converted into mechanical energy first.	High efficiency as oceanic wave energy directly impacts piezoelectric elements.
Power Loss	Minimal power loss in the piezoelectric conversion process	Moderate power loss due to mechanical conversion.	Minimal power loss as direct wave energy is utilized.
Environmental Dependability	Depends on traffic flow for consistent energy generation	Depends on wind patterns for reliable energy production.	Depends on oceanic wave patterns for continuous energy supply
Site placement	Suitable for locations with high vehicular traffic, like port entrances	Ideal in areas with consistent wind conditions.	Requires placement in oceanic environments with significant wave activity.
Technological Maturity	Mature technology is widely used in various applications.	Mature technology with established wind turbine systems	Changing technology, comparatively more recent in the field
Sustainability	Sustainable as it utilizes mechanical energy from vehicle pressure.	Sustainable by harnessing wind energy, a renewable resource.	Highly sustainable, tapping into renewable oceanic wave energy.
Versatility	Limited to locations with vehicular traffic	Somewhat versatile but tied to wind conditions.	Limited to oceanic environments with significant wave activity.

Reliability and Durability	Reliable and durable with minimal moving parts.	Reliable but may require maintenance due to moving parts	Reliable and durable with minimal moving components
Safety	Safe for both users and the environment	Safe with proper safety measures around turbines.	Safe with minimal impact on marine life.
Cost-Effectiveness	Cost-effective due to simple setup.	Moderate cost due to wind turbine infrastructure	Cost-effective for harnessing abundant wave energy
Initial Setup	Low initial setup costs	Moderate setup costs due to turbines	Moderate setup costs in marine environments
Ease of Maintenance	Low maintenance with minimal moving parts	Moderate maintenance due to turbines	Low maintenance in harsh marine conditions
Mass Production ability	Easily scalable for mass production.	Scalable but with turbine manufacturing considerations	Scalable for mass production in suitable regions

The analysis of the three approaches to producing piezoelectric energy shows significant distinctions. The most energy-efficient approach is Approach 1, which uses speed breakers, while Approach 2, which uses wind turbines, is closely behind. Approach 3, which uses ocean waves, exhibits some efficiency but requires more technological advancement. Environmental dependability is a strength that all approaches have in common. Site selection varies greatly depending on the approach, Approach 2 requires windy places, Approach 3 is best suited for coastal areas, and Approach 1 needs specialized locations for speed breaker barriers. While there are differences in technical maturity, Approaches 1 and 2 profit from modern technologies. Sustainability is a collective advantage, and all approaches place a high priority on safety. The choice of approach is affected by factors such as cost-effectiveness, initial setup, maintenance, and mass production potential.

2.5 Conclusion

In this chapter, we looked into a variety of design techniques in the constant search for a sustainable and energy-secure era. Each solution is an offering to the potential of piezoelectric energy generation. It has shown us how to get to a wider energy mix and away from our precarious reliance on limited and resource-intensive resources.

Our first approach is a demonstration of the originality of using piezoelectric materials to gather energy from everyday pressure. We've developed a device that reacts to vehicle pressure by carefully positioning piezoelectric crystals beneath the speed breakers of a port's entrance gate. This strategy tackles the requirement for sustainable energy in port operations as well as an everyday scenario. The careful planning that went into developing and simulating this approach shows the steps taken to ensure cost-effectiveness and sustainability.

The second approach uses the energy of wind turbines to trigger polyurea-coated cantilever beams to deflect. Due to potential differences created when the turbine blades make contact with these beams due to wind flow, electrical current is generated. This strategy's adaptability to the windy circumstances that are frequently present in port areas. It reflects the concept that incorporating sustainability into the present system can be done easily. It aims to make port surveillance systems self-sustaining.

In addition, the third method involves using piezoelectric oceanic wave energy converters (OWECs) to capture the kinetic energy of waves in the ocean. We've opened up the possibility of using ocean waves as a sustainable energy source by converting the stress generated by piezoelectric transducers into electrical energy. The energy source is about going through a revolution with the prospects of an environmentally harmless, lightweight, and compact generation of electricity in port operations.

In the chapters that follow, we go more into the complex analyses and specifics of these approaches in an effort to provide insight into the best route to take for more sustainable green energy. Through deploying different approaches, we may mitigate the future energy crisis, adaptability, and a firm commitment to environmental responsibilities.

Chapter 3: Use of Modern Engineering and IT Tools [CO9]

3.1 Introduction

Modern engineering and information technology tools have become important in helping to create creative solutions to complex issues in today's quickly expanding technological ecosystem. This is particularly seen in our project, where we use the power of cutting-edge tools to produce a reasonably priced and environmentally friendly energy solution. Our project's successful completion is significantly dependent on a seamless combination of hardware and software elements, each of which was carefully chosen to enhance effectiveness, accuracy, and dependability. In this section, we explore the numerous modern engineering and IT tools that have been essential to the design, simulation, data analysis, and implementation of various aspects of our project. Our use of these tools is a commitment to creativity in the search for environmentally friendly energy options as well as an icon of the revolutionary power of technology in the area of electrical engineering. The hardware and software tools that enabled us to successfully design, develop, and implement our energy harvesting system are described in depth in the sections that follow. These resources have improved our project's efficiency while also broadening our perspectives on environmentally friendly energy options.

3.2 Select appropriate engineering and IT tools

3.2.1 Hardware portion

- Digital Oscilloscope: A digital oscilloscope is an indispensable tool for capturing and analyzing the output waveform and values of piezoelectric devices. When used in conjunction with piezoelectric materials, a digital oscilloscope can capture and display the waveform generated by the material, allowing for precise analysis and measurement of the voltage and current. By displaying the captured signals on a digital screen, users can easily observe and analyze the waveform, enabling them to obtain important information about the performance of the piezoelectric material. Furthermore, the features of modern digital oscilloscopes, such as the ability to perform automatic measurements and waveform math functions, make it easier for users to analyze and interpret the data. As such, digital oscilloscopes have become a vital tool for engineers and scientists working in various fields that utilize piezoelectric devices

- Multimeter: A multimeter is a versatile tool used to measure electrical properties such as voltage, current, and resistance. It is commonly used by engineers and technicians to diagnose and troubleshoot electrical problems in various devices and circuits. In our project, we used a multimeter to measure the output voltage generated by the piezoelectric material. This measurement was crucial for testing and optimizing the efficiency of our energy harvesting system.

- Arduino Uno: The Arduino Uno serves as the core microcontroller for our RC Truck, offering versatility and ease of use. It has an Atmega328P microcontroller, which offers enough processing capability for our tasks. Due to its open-source nature, a sizable community and an abundance of online resources are ensured. The operation of our Bluetooth RC car depends on its ability to easily communicate with a variety of motor speeds through the motor driver and multiple input and output ports.

- Wireless Communication: In our Bluetooth RC car, wireless connectivity is essential for remote control. The main means of connection between the smartphone as a remote and the Arduino-based car is Bluetooth. For smooth connectivity, HC-06 Bluetooth modules are used. Although Bluetooth is convenient, it is important to be aware of its short range, which, under ideal circumstances, is only about 100 meters [23]. This wireless connection enables real-time control and feedback, which makes our RC car interactive.

3.2.2 Software portion

- VS Code: Visual Studio Code is a code editor that supports various development operations like debugging, task running, and version control. This editor was used by our group to develop a piezo calculator tool. HTML, CSS, and JavaScript were the three primary programming languages we used to create this tool. Based on their parameters, customers can utilize the tool's simple interface to determine the electrical output of piezoelectric crystals. The development process was quick and easy because of Visual Studio Code's simplified features and support for numerous programming languages.

- Rhinoceros: Rhinoceros, also known as Rhino, is a 3D modeling software used for designing and creating complex 3D models. It is widely used by professionals in various fields, including architecture, industrial design, and engineering. Rhino offers a vast range of tools and features that enable users to create, edit, and visualize 3D models quickly and efficiently. Its user-friendly interface makes it accessible to both beginners and experts. With Rhino, users can create detailed 3D models that can be used for various purposes, including visualizing scenarios and testing designs. Its rendering capabilities allow users to produce high-quality images and animations of their designs [24].

- Altium Designer: The automatic incorporation of 3D design capabilities into Altium Designer with PSpice is a noteworthy feature. Users can design 3D models of their PCBs and components, which enables accurate visualization and physical layout verification. This integration is essential for making sure that electronic parts fit inside enclosures without interference or collision [25]. Also, by modeling heat dissipation and airflow, the 3D design features allow designers to evaluate thermal performance, increasing the overall reliability of the design. In conclusion, the 3D design tools of Altium Designer are vital for improving the mechanical and economic elements.

- Google Drawing: Google Drawing is a web-based vector graphics editor that allows users to create and edit diagrams, flowcharts, and other visual representations. It is a useful tool for creating block diagrams to visualize ideas, processes, and workflows.

Google Drawing is user-friendly and easy to use, with a wide range of pre-made shapes and templates available to make the diagramming process more efficient.

- Arduino IDE: An essential tool is the Arduino Integrated Development Environment (IDE). It is an open-source, user-friendly platform made to make it easier to program Arduino microcontrollers. Code creation is simplified by the IDE's code editor, which includes tools like syntax highlighting and auto-completion. It ensures connectivity with a variety of projects by supporting a large variety of Arduino boards, shields, and libraries.

3.2.3 Circuit simulation

- Proteus 8 Professional: Proteus is a comprehensive development platform that covers the entire product development process from concept to design completion. One of the platform's primary advantages is its intelligent principle layout, which ensures efficient circuit design. Additionally, it features hybrid circuit simulation and accurate analysis, enabling designers to accurately predict the behavior of their circuits before they are built. Proteus also supports single-chip software debugging and co-simulation of single-chip and peripheral circuits. By using Proteus software, designers can build and test their software designs, comparing the simulation results to expected outcomes. Proteus is compatible with a range of common single-chip models and generic peripheral models, allowing for a high degree of flexibility in the design process. Its dynamic simulation capabilities, which are based on frames and animation, provide excellent visual effects that meet the needs of modern design requirements. Additionally, the software supports various sensors, which can be easily incorporated into simulation designs, making the simulation process more efficient and effective.

- MATLAB Simulink: MATLAB Simulink is a simulation and modeling platform that provides an intuitive graphical interface for designing complex systems. One of its primary advantages is its ability to support multiple domains, including mechanical, electrical, and control systems, in a single environment. With Simulink, designers can quickly create and test models, allowing them to detect and address potential issues early in the design process. Simulink provides extensive analysis and visualization tools that help designers gain a deeper understanding of the behavior of their systems. Additionally, it offers powerful optimization algorithms that enable designers to optimize their systems' performance according to a range of criteria. The platform's extensive library of pre-built models, which include standard components, algorithms, and interfaces, further enhances its flexibility and usability. Additionally, Simulink supports the integration of custom libraries, enabling designers to create models that meet their specific needs. In summary, MATLAB Simulink is a powerful and versatile simulation and modeling platform that provides designers with a range of tools to create complex systems. Its ability to support multiple domains, provide extensive analysis and visualization tools, and generate optimized code for embedded systems makes it an indispensable tool for modern engineering design.

- EasyEDA: EasyEDA is a web-based EDA tool package that allows hardware engineers to publicly and privately generate, model, exchange, and evaluate schematics, simulations, and printed circuit boards [26]. EasyEDA's adaptability is one of its best qualities. A complete set of PCB design tools, such as schematic capture, PCB layout, and a component library, are offered. Within the same platform, users can easily switch from schematic design to PCB layout. The application also facilitates cooperation, allowing groups to collaborate on projects concurrently and regardless of their geographical location. It's a great option for individuals wishing to finish their electronics projects due to its versatility and user-friendly interface.
- PSpice: PSpice is a popular simulation software for the design and analysis of electrical circuits. One of the most widely used tools in the field of electronics for learners is PSpice, which was created by Cadence Design Systems [27]. The extensive feature set that PSpice provides for simulating and analyzing electrical circuits makes it an essential tool in the development and testing of electronic devices. The software allows users to create and analyze complex electronic circuits, including analog, digital, and mixed-signal designs. Users can forecast how a circuit will react in different settings because of PSpice's accurate component and ambient modeling. A comparison table between different software that was initially selected is shown below:

Table 3.1: Software comparison

Software Name	**Portable**	**Moderate PC Specs**	**Crash issue**	**Graph**	**Visualization**	**Naming**	**Cloud connecting**	**Image processing**
Proteus 8	✓	✓	✓	✓	✓	✓	X	X
MATLAB Simulink	✓	X	✓	✓	✓	✓	✓	✓
PSpice	X	X	X	✓	✓	X	X	X
EasyEDA	✓	✓	✓	✓	✓	✓	✓	X
Rhinoceros		✓			✓	✓	✓	X
Altium Designer	✓	X	✓	X	X	✓	X	X

We chose Proteus 8 Professional (v8.13) for simulations after comparing a number of variables because of its huge online forums, plenty of information, and user-friendly interface. Additionally, MATLAB supports our project requirements for data analysis and modeling owing to its comprehensive library support and cloud connectivity. Rhinoceros is our preferred choice for 3D design because it provides a user-friendly interface and effective cloud integration for visualization and design.

3.3 Use of modern engineering and IT tools

3.3.1 Hardware portion

- Digital Oscilloscope: The digital oscilloscope is an important tool in our project for verifying the functioning of piezoelectric disks. The oscilloscope allows us to properly measure and show measurements like peak-to-peak values and RMS values, which are essential to our energy harvesting system. These measurements are crucial for determining how well our energy conversion process works and confirming that it adheres to our project requirements. The oscilloscope provides real-time feedback on the condition of the circuit during the circuit development process, assisting us in quickly identifying and fixing any problems. This assures that the technological advances will work as intended. The oscilloscope is a vital tool for engineers and scientists working on projects involving piezoelectric devices because of its capacity to produce graphs and offer automatic measurements that simplify the processing of data. The working status of our prototype is shown in the image below, which demonstrates how important the oscilloscope was to the outcome of our research.

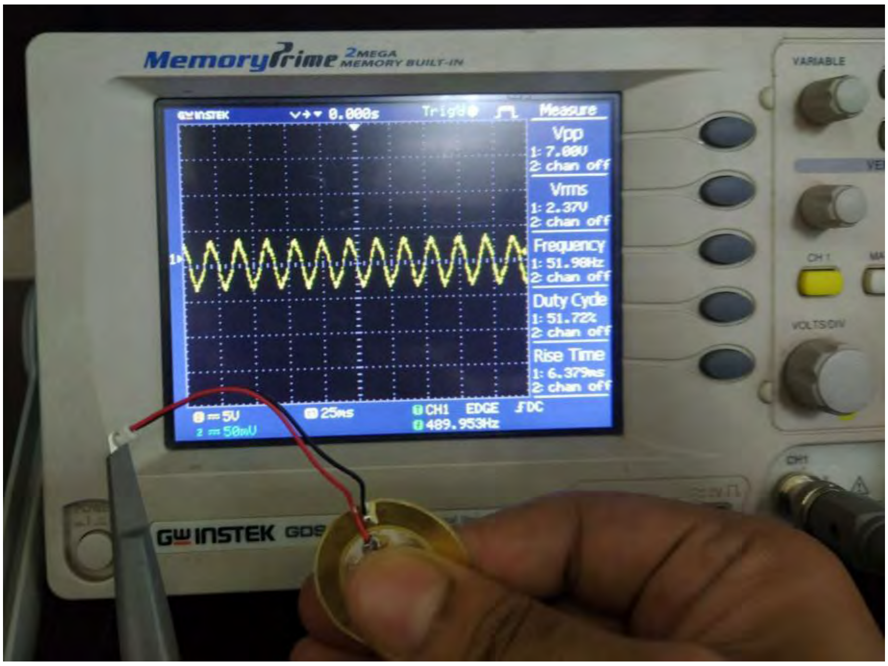


Figure 3.1: Use of the Digital Oscilloscope

- Multimeter: A vital tool in engineering and electrical troubleshooting, the multimeter is an adaptable instrument used for measuring electrical properties like voltage, current, and resistance. The multimeter was a necessary tool for many crucial activities in our project. It was crucial for assessing the performance of piezo disks in various configurations (series or parallel connections), determining wire continuity, and continuously monitoring voltage data obtained by the piezoelectric material. In short, the multimeter proved to be an invaluable tool, serving as a lifeline throughout our project, ensuring precise measurements, and assisting in ensuring the successful implementation of our energy harvesting system.

3.3.2 Software portion

- VS Code: The design and development of a specific piezo calculator tool was made possible due to the versatility of Visual Studio Code, a code editor, which was crucial to the accomplishment of our project. We took advantage of the editor's robust capabilities, which include debugging, task execution, and version control, by using HTML, CSS, and JavaScript as our main programming languages. This allowed us to use JavaScript to implement complex calculations for piezoelectric crystals, HTML to create a user-friendly interface, and CSS to influence the calculator's design. We accelerated the development of the solution by utilizing Visual Studio Code, taking advantage of its simplified features and support for numerous programming languages. The tool's correctness and functioning were checked during development by running it in the Chrome browser without any problems. Here is an image of our piezo calculator in use as a reference. It shows how well current development tools work together and the outcome of our project,

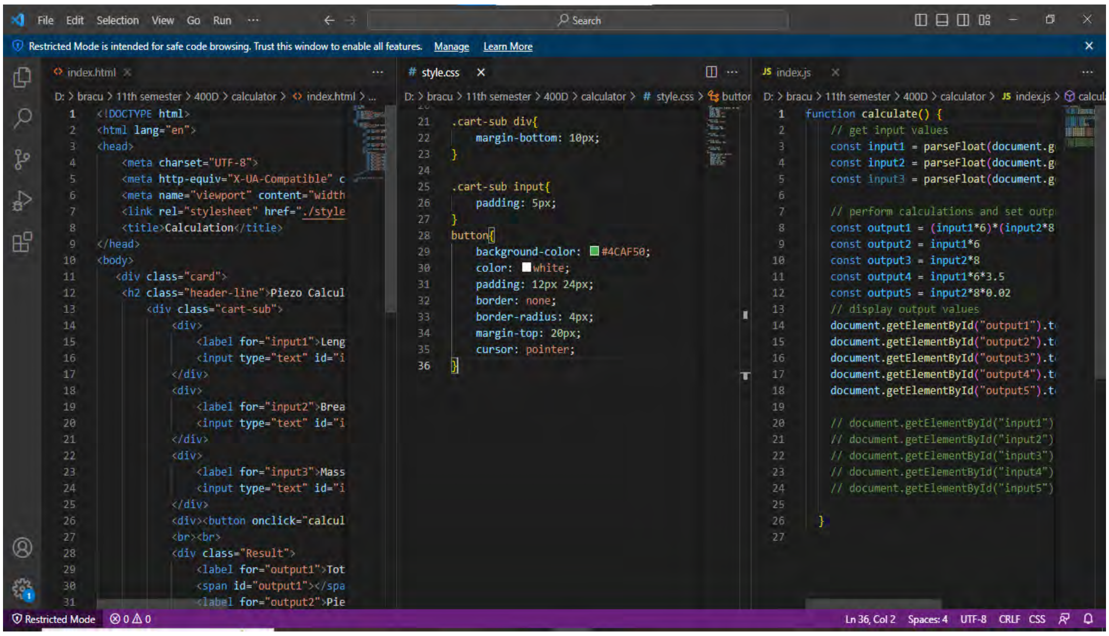


Figure 3.2: The HTML, CSS, and Javascript in the Visual Studio Code editor

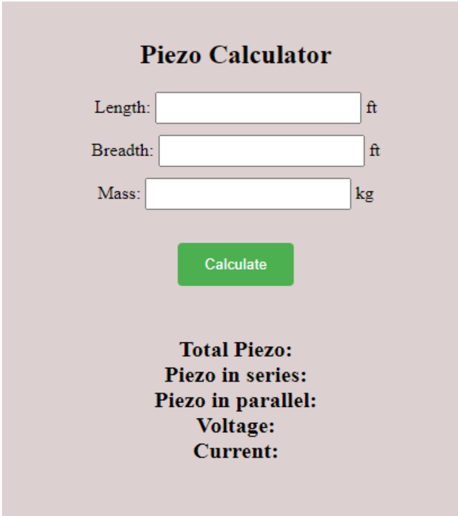


Figure 3.3: Output of the VScode in Chrome browser.

- Rhinoceros: Rhinoceros, often known as Rhino, is a powerful 3D modeling software noted for its ability to create complex and detailed 3D models. Rhino's broad set of tools and features draws skills from a variety of industries, including engineering, industrial design, and architecture, who use it to quickly and efficiently build, modify, and visualize complex 3D designsThis involved precisely designing crucial features, like the suggested speed breakers with incorporated piezoelectric parts, surveillance system configurations, road layouts, and more. For the third approach, we created a detailed ocean setting with a built-in piezo harvesting device. Rhino's rendering prowess allowed us to create high-quality graphics and animations, which were essential for presenting and reviewing our designs. Below is a picture showing how our 3D scenario in Rhino is now functioning,

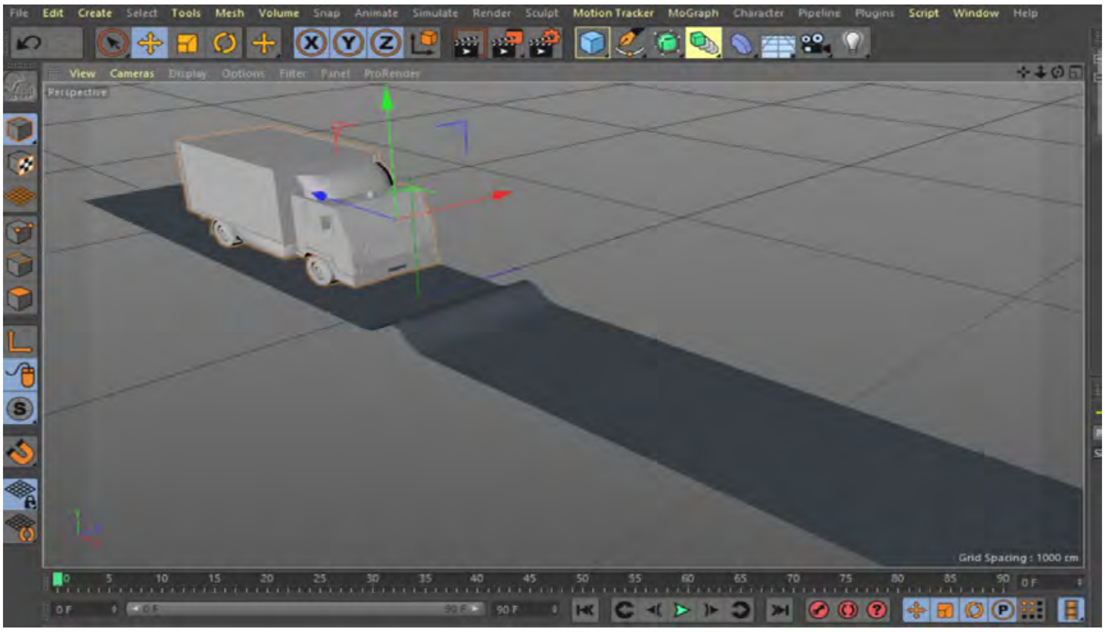


Figure 3.4: The working figure of Rhinoceros

- Google Drawing: An essential tool in our study was the versatile web-based vector graphics editor Google Drawing. Our project's approaches, methodology, and Gantt chart were all clearly and succinctly displayed in block diagrams due to its user-friendly interface and wide library of pre-made shapes and templates. This teamwork tool enabled real-time editing and feedback sharing among team members, simplifying the development of our project and improving its clarity. Below is a picture showing the functioning state of the Google Drawing diagrams used in our project for reference,

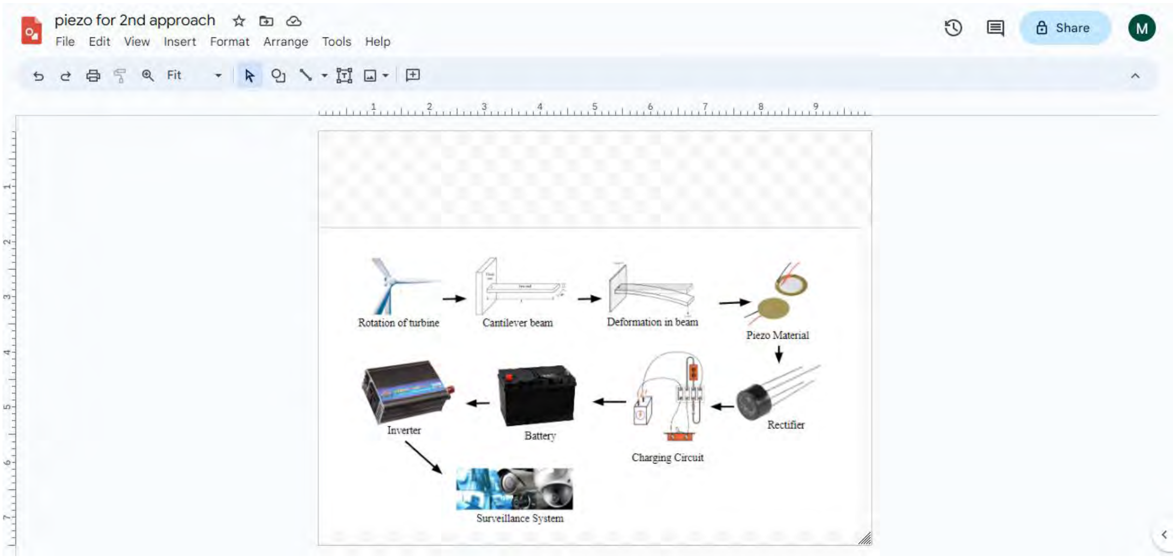


Figure 3.5: The working interface of Google Drawing

- Arduino IDE: The Arduino Integrated Development Environment (IDE), which provides a user-friendly, open-source platform for programming Arduino microcontrollers, was essential to the success of our project. With tools like syntax highlighting and auto-completion, it made writing code easier. The IDE made sure that our project connected to numerous Arduino boards, drivers, and libraries without any problems. In particular, the serial display made it easier to troubleshoot and communicate with the Arduino board in real time. This IDE functioned as a pillar for turning abstract concepts into practical projects, enabling us to program our RC vehicle for remote control and efficiently demonstrate the proper operation of the generated electricity.

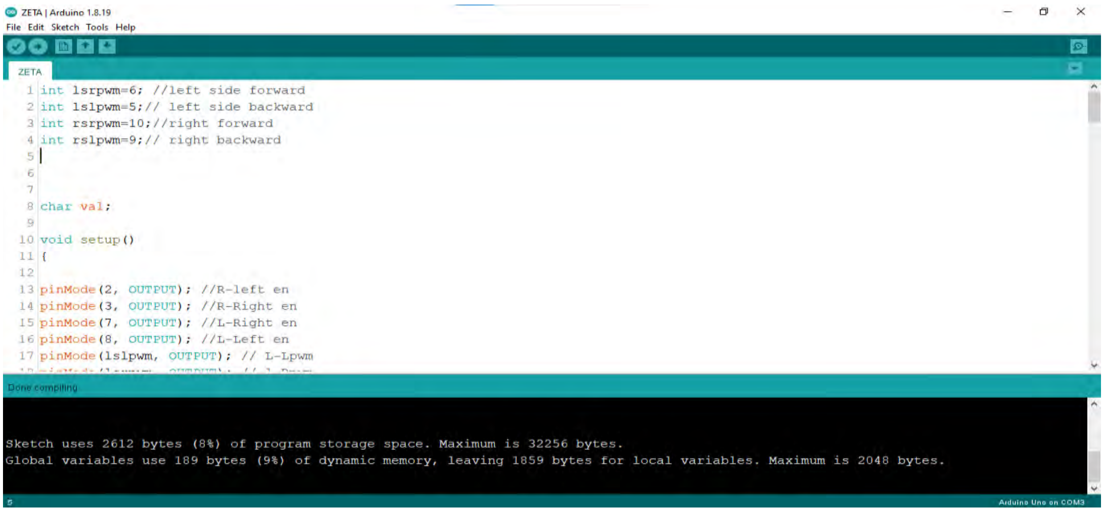


Figure 3.6: The interface of Arduino IDE

3.3.3 Circuit simulation:

- Proteus 8 Professional: Our primary simulation tool, Proteus 8 Professional, proved to be an all-encompassing platform for the development of our project. The effectiveness of our circuit design, a crucial part of our energy harvesting system, was guaranteed by its clever fundamental architecture. We began with single piezo disk triggers and worked ourselves through creating a full wave rectifier, charging circuit, and inverter, all of which came with precise graphing capabilities. These elements were easily incorporated into a unified circuit simulation through the software. One of the software's most notable qualities was its ability to work with numerous single-chip models and peripheral models, which gave us a tremendous amount of design flexibility. Our energy harvesting system's precision and dependability were greatly enhanced by the ability to test different circuit configurations, supported by real-time graphing and voltage and current value monitoring. The figure below shows our proteus circuit simulation in its operational state:

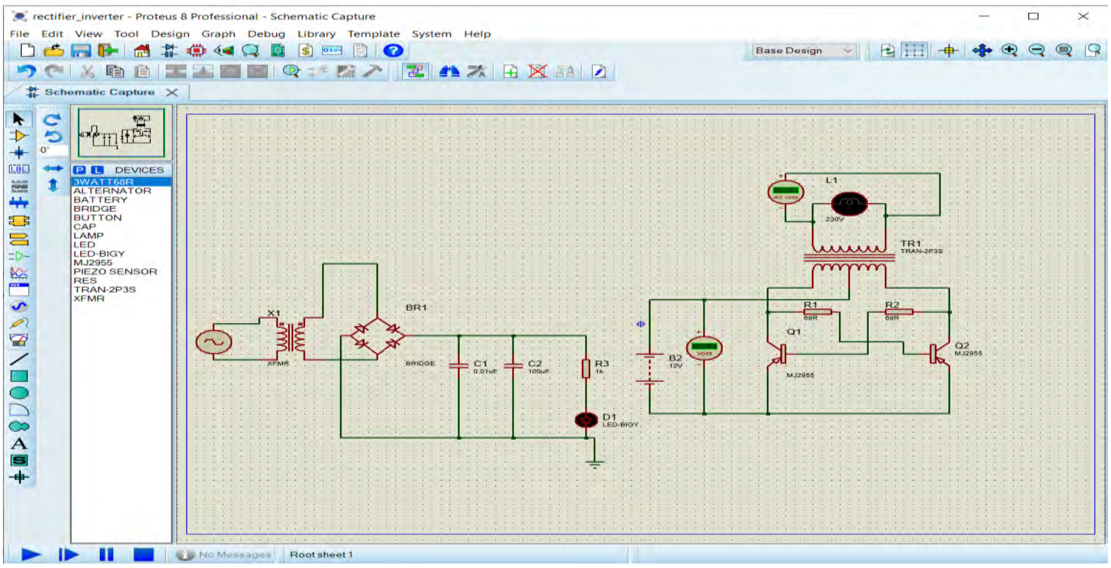


Figure 3.7: The Proteus software's functional user interface

● MATLAB Simulink: MATLAB Simulink, a powerful simulation and modeling platform, played a pivotal role in our project, particularly in the context of our second approach. This user-friendly tool, lauded for its graphical user interface, was important in precisely and effectively building and testing complicated systems. The platform's comprehensive set of research and visualization capabilities gave us a deep understanding of how our system behaved, which was essential for refining our approach to obtaining energy. We were also able to fine-tune system performance in accordance with a variety of parameters thanks to Simulink's powerful optimization algorithms, which increased overall efficiency. Simulink's extensive model library and support for custom libraries improved the usability and flexibility of our designs.

Afterward, MATLAB Simulink was a crucial tool for modern engineering design. Its benefits were clearly demonstrated in our second strategy, which allowed for accurate modeling, evaluation, and optimization of our energy harvesting system.

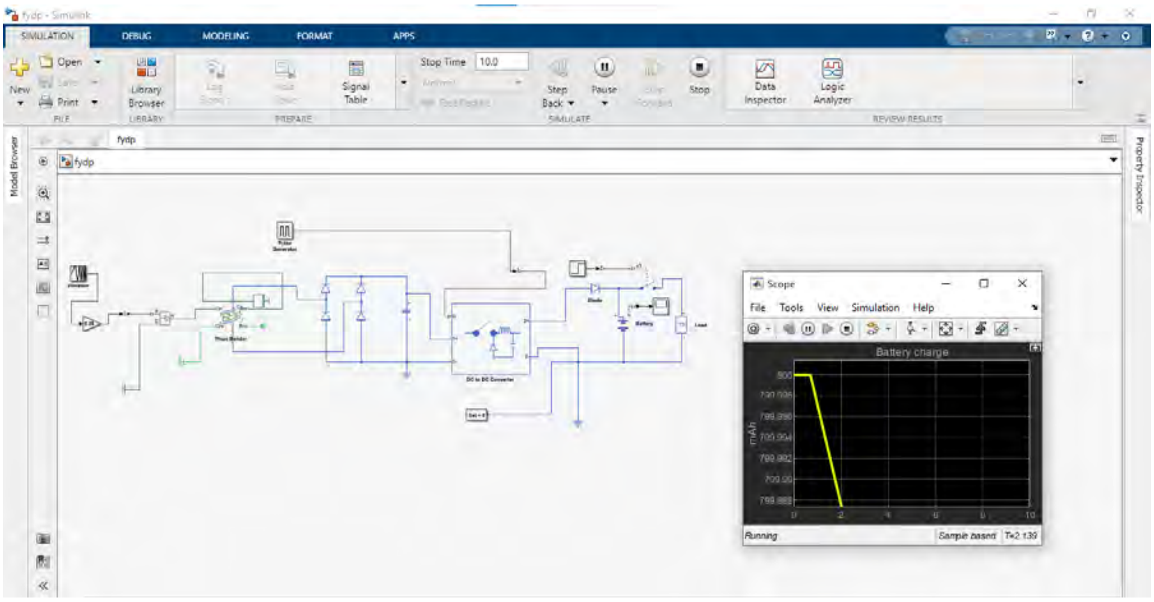


Figure 3.8: The interface of MATLAB Simulink

● EasyEDA: EasyEDA, a web-based Electronic Design Automation (EDA) tool package, stands as a pivotal asset for hardware engineers seeking to create, model, exchange, and assess schematics, simulations, and printed circuit boards. This adaptable platform provides a full range of PCB design capabilities, including schematic capture, PCB layout, and a sizable component library. The PCB design for our final prototype, created with EasyEDA, is shown in the image below in its operational form,

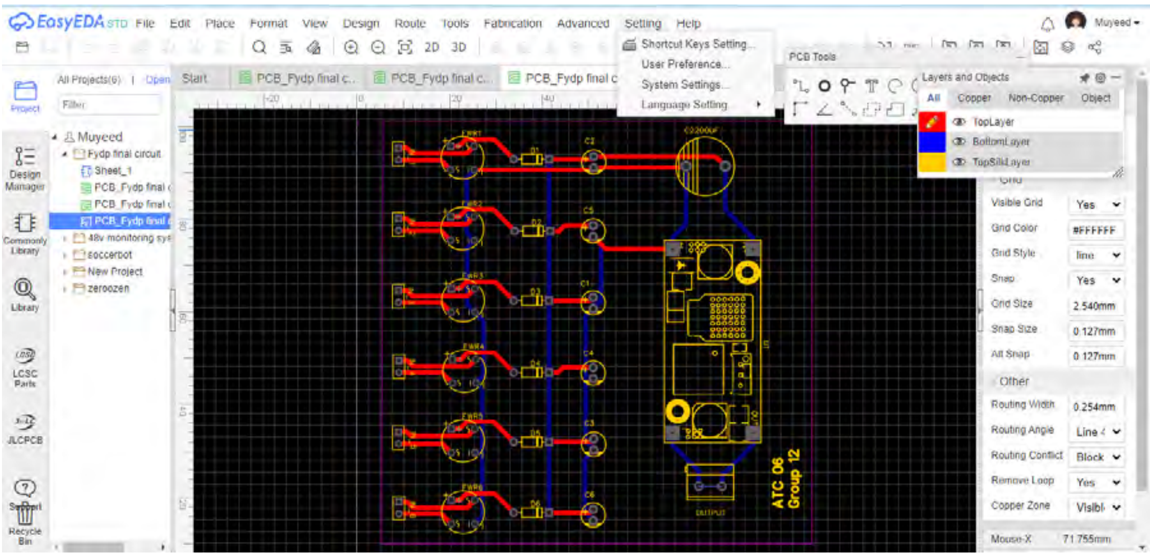


Figure 3.9: The Easy EDA web interface in proceeding

3.4 Conclusion

Modern engineering and IT tools are essential in today's rapidly developing world of technology for solving complex problems with solutions that are original and innovative. Our selection and skillful utilization of a wide variety of hardware and software resources were vital to the deployment of our energy harvesting system. Each tool was selected with a clear understanding of how it could improve the effectiveness, precision, and dependability of our project.

Our decisions about hardware were carefully made to accomplish specific objectives. In order to precisely measure and visualize crucial electrical properties, tools like the digital oscilloscope and multimeter have proven to be helpful. This has allowed us to monitor and enhance the performance of our piezoelectric materials. We were able to remotely control and get data from our prototype using the Arduino Uno and HC-06, notably improving the adaptability of our energy harvesting system.

To address various areas of our project, we used a wide range of software. We were able to create a user-friendly piezo calculator using HTML, CSS, and JavaScript via Visual Studio Code. We were able to visualize our concepts for a variety of methods through Rhinoceros' 3D modeling, which made our project more visual. We were able to more effectively and concisely communicate our thoughts by using Google Drawing to make block diagrams. We were able to demonstrate how to successfully integrate our generated electricity into a useful application by using our RC vehicle as a development platform using the Arduino IDE.

Our selections in the area of circuit simulation and analysis were equally careful. MATLAB Simulink facilitated proper graphing and validation, ensuring accuracy and reliability. We were able to model the piezo equivalent circuit within the larger system environment using Proteus 8 Professional, which helped us make designs. The PCB design process was expedited with Easy EDA, resulting in the perfect integration of components into our prototype.

Chapter 4: Optimization of Multiple Design and Finding the Optimal Solution [CO7]

4.1 Introduction

The initial step in implementing the project idea, based on the project proposal, involves structuring the foundation. There are several ways to accomplish the aim once the proposal is formed and the project's purpose is identified. However, determining the most efficient path can only occur once all potential approaches have been thoroughly explored and optimized. Consequently, we conducted a comprehensive analysis of multiple design approaches for the project. In our project, the selection of the optimal approach for power generation through piezoelectric material will be made only after completing software simulations for all design options. We will carefully evaluate and compare the results from various designs to deduce the most optimal design for our project.

4.2 Optimization of multiple design approach

4.2.1 Approach 1: Generating Electricity through piezo-electric crystal by Pressure

<u>Piezoelectric Material:</u>

The most commonly used piezoelectric for energy harvesting is PZT (lead zirconate titanate). To induce a maximum charge on these, it must be used in its SRF (self-resonant frequency) range. Thus, considering the operation region to be in the resonant frequency, a piezoelectric can be approximated to have an electrical equivalent consisting of a parallel combination of a high resistance R, capacitance C, and a sinusoidal current source I as shown in the figure below [28] [29].

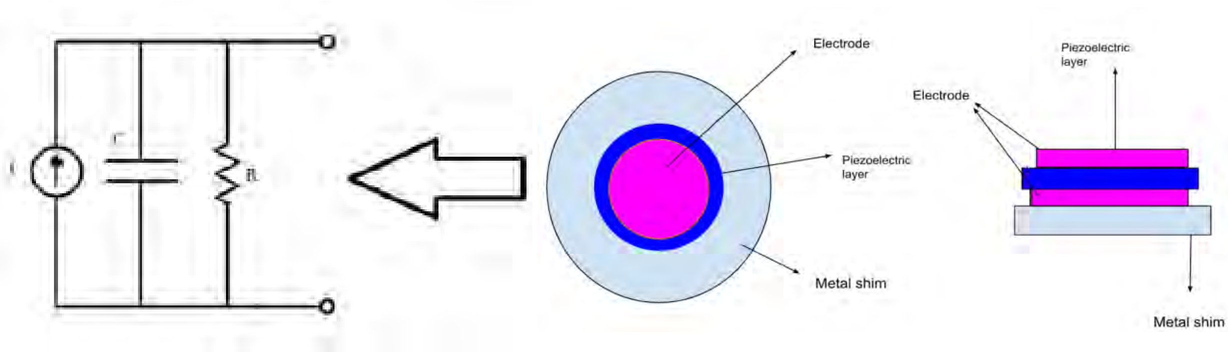


Figure 4.1: Piezoelectric diaphragm along with transducer equivalent circuit at resonance

Piezo Simulation:

Before Simulating

After Simulating

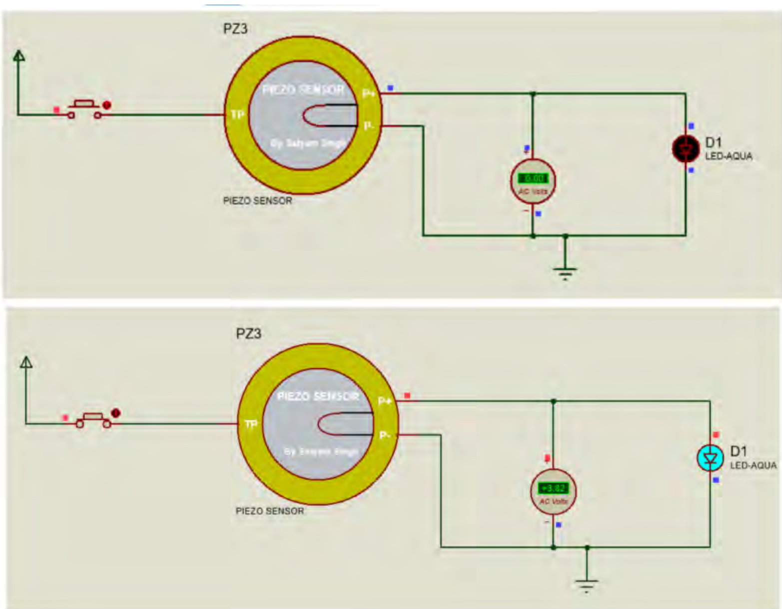
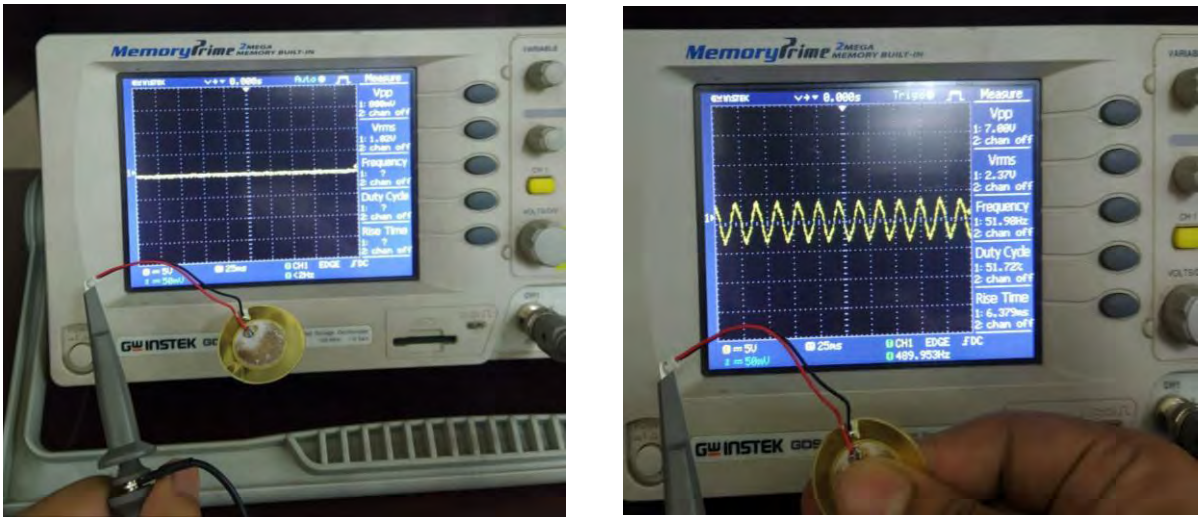


Figure 4.2: Simulation of a single piezoelectric sensor

In Proteus, there is a built-in piezo sensor. This piezo sensor gives an output voltage of 3.82. This is an AC voltage, so we need to convert it to a DC voltage. The constraint of this output is that it provides a constant voltage. Even so, a physical piezoelectric sensor cannot give a constant voltage.



(a) (b)

Figure 4.3: Digital Oscilloscope output

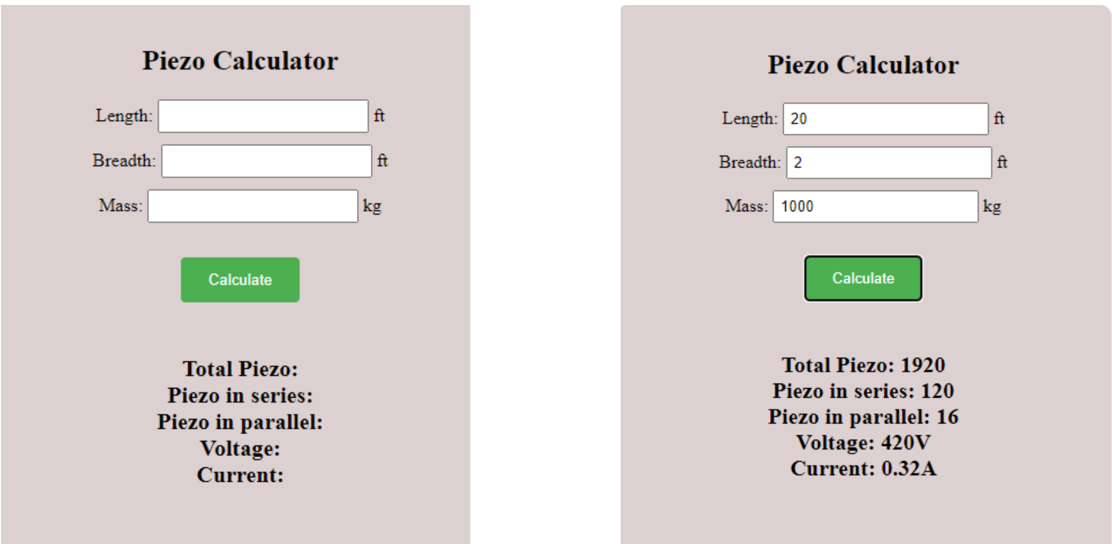
For better output result or voltage we used a physical piezo sensor. To get the output voltage we connected the piezo sensor with the digital oscilloscope. In Figure 4.3(a) we can see that there is no wave when there is no pressure on the piezo sensor. In Figure 4.3(b) the digital oscilloscope shows that the V_{pp} (peak-to-peak voltage) is 7V. It means that the voltage of that piezo is 3.5V. We varied the force to get different outputs for different forces. Yet the piezo sensor gives a maximum voltage of 3.5V despite any higher force. For micro force or pressure, it gives different voltages but after a certain force or pressure it gives 3.5V. So, from this, we considered that the maximum voltage will be 3.5 from a single piezo sensor.

Piezo Calculator:

The Piezo Calculator is a unique tool designed to determine the required number of piezoelectric elements needed for a given application based on user input data. Using the calculator, users are prompted to input the length and breadth of the application area in feet, as well as the mass in kilograms.

Based on these inputs, the piezoelectric calculator calculates the total piezoelectric element required for the application, as well as the number of elements needed in series and parallel, individually. Additionally, the calculator generates the voltage and current produced by the piezoelectric elements.

Overall, the piezoelectric calculator is a valuable tool for anyone working with piezoelectric elements, providing an easy-to-use and efficient solution for determining the number of elements required for a given application. The piezo calculator simplifies the process of selecting the appropriate piezoelectric elements, saving time and effort in the design process.



(a) (b)

Figure 4.4: Piezo Calculator

Here, we gave an assumption length (20 feet) and breadth (2 feet) for the speed breaker as our input and our expected mass of the vehicle (1000 kg). After calculating, we found that the total number of we need to install is 1920. Among the 1920 piezo, 120 piezo disks will be connected in series and 16 such series-connected piezo arrays will be in parallel. By installing and connecting the piezos we got about 420 volts and 0.32 A current.

For calculation, we selected that we could place or install six piezo disks per foot on the length side and eight piezo disks per foot on the breadth side. The diameter of the piezo disk that is available in the market is 35mm. The piezo disks that will be on the length side those piezo disks will be connected in series and those series-connected piezo arrays will be connected in parallel on the breadth side.

$$\therefore \text{Piezo in series} = \text{Length} * 6 = 20*6 = 120$$

$$\therefore \text{Piezo in parallel} = \text{Breadth} * 8 = 2*8 = 16$$

Again, we found in both simulation and hardware piezo the output voltage of a single piezo is 3.5. So, when we connect the piezo disks in series it multiplies the voltage. Moreover, a single piezo disk can generate 0.02A current. When piezo disks are connected in parallel it multiplies the current.

$$\therefore \text{Voltage} = \text{Length} * 6 * 3.5 = 420V$$

$$\therefore \text{Current} = \text{Breadth} * 8 * 0.02 = 0.32A$$

In the piezoelectric material section, we saw that the piezo sensor gives a maximum voltage after a certain amount of mass. So, for big mass, the output voltage and current doesn't change.

<u>Full-wave rectifier:</u>

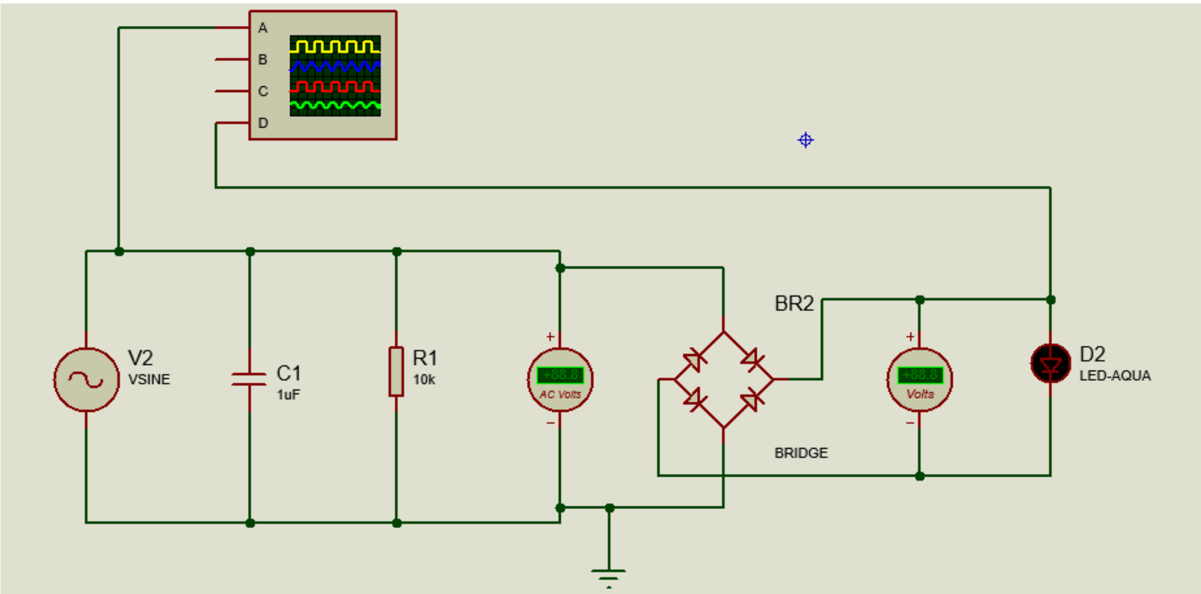


Figure 4.5: Full-wave Rectifier

We designed a full-wave rectifier bridge to convert the generated AC current into DC and charge up a battery. To test the performance of the circuit, we built a simulation in Proteus software. We placed an AC voltmeter just after the equivalent circuit of the piezo to measure the voltage before rectification, and a DC voltmeter to measure the voltage after rectification. Additionally, we used an oscilloscope to observe the waveform before and after rectification. This allowed us to compare the AC and DC waveforms and confirm that the rectification process was successful.

The full-wave rectifier bridge is a crucial component in piezoelectric energy harvesting systems, as it ensures that the generated AC current is converted into a stable DC voltage suitable for charging batteries. The use of Proteus software enabled us to build and test the circuit in a simulated environment, saving time and resources in the design process. The tested result:

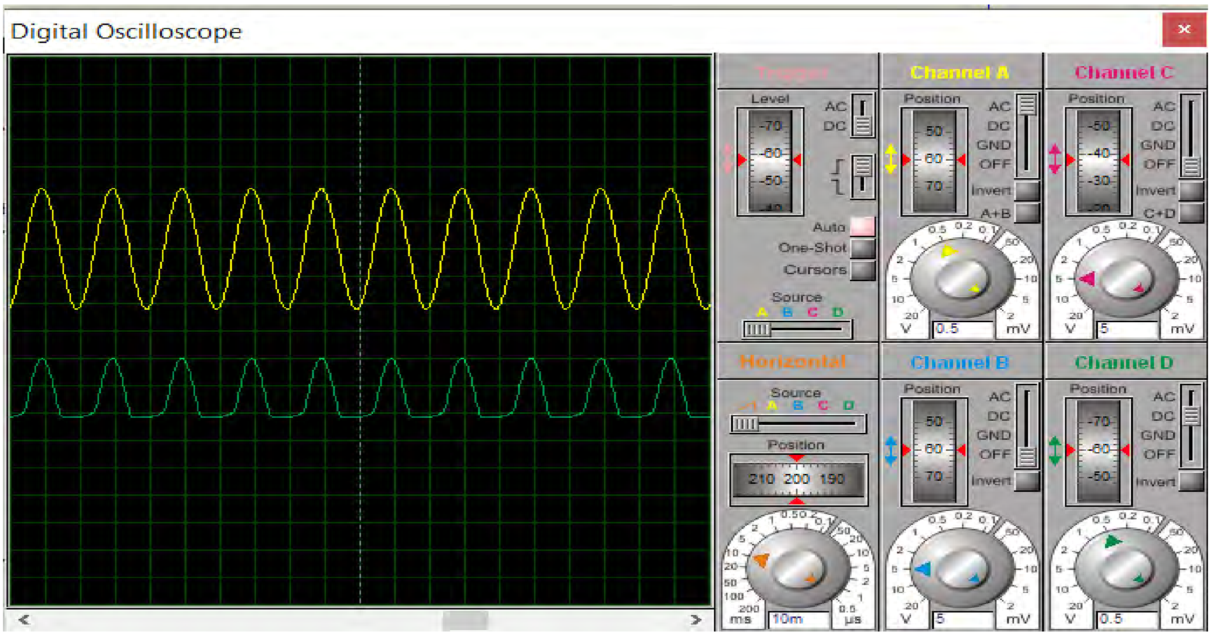


Figure 4.6: Oscilloscope Output

Overall, our design and testing of the full-wave rectifier bridge demonstrate the potential for piezoelectric energy harvesting to power a range of applications, from small sensors to larger devices requiring continuous power.

<u>Charging Circuit:</u>

The charging circuit we built in Proteus is an efficient solution to charge a battery from an AC source. It includes a green LED to indicate the charging status and a red LED to indicate when the battery is fully charged. A voltmeter next to the battery gives information on the battery's current voltage in addition. This aids in detecting the battery's charge level and whether additional charging is necessary. The battery's state of charge, including when it is fully charged or still being charged, can also be determined using the voltmeter. This circuit is perfect for usage in systems that we have created or in ports where battery charging is necessary. The voltmeters make it simple to check on the battery's charging progress, ensuring peak performance and a long battery life.

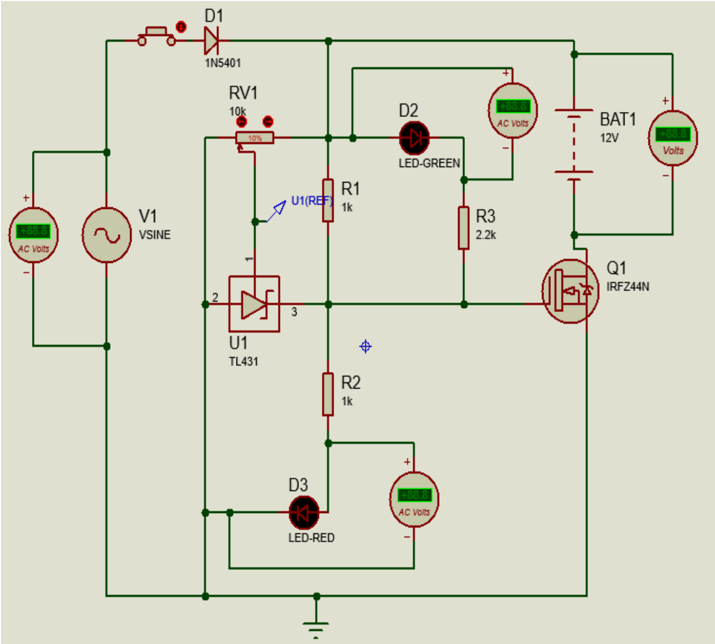


Figure 4.7: Charging Circuit

Inverter:

The inverter circuit built in Proteus is a crucial component in the surveillance system of the port, as it enables the battery's 12V output to be stepped up to 230V, the required voltage for the system to function. The circuit incorporates a step-up transformer that boosts the voltage to the desired level. Additionally, to monitor the state of the output, voltmeters are placed before the battery and after the transformer. This ensures that the inverter circuit is functioning correctly and producing the necessary output voltage. With this circuit in place, the surveillance system can run without interruption, as the inverter circuit ensures that the voltage requirements are met.

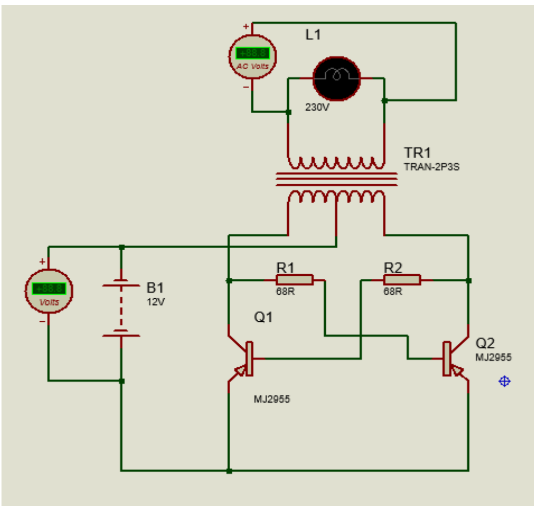


Figure 4.8: Inverter

Comprised Circuit:

Here, we have integrated all individual circuits into a single circuit. We used the equivalent circuit of the piezo sensor [28] [29]. The reason behind using an equivalent circuit is if we use the built-in piezo sensor we cannot vary the voltage. After that, we connected the full wave rectifier as we needed to convert the AC voltage to DC voltage. As we know, piezo gives AC voltage. We also know that the piezo gives unstable voltages. So, we connected a voltage regulator so that it gives a constant voltage. To store this voltage, we need a battery. So, to charge that battery we connected a charging circuit. After that, we connected an inverter because the loads would be the AC loads.

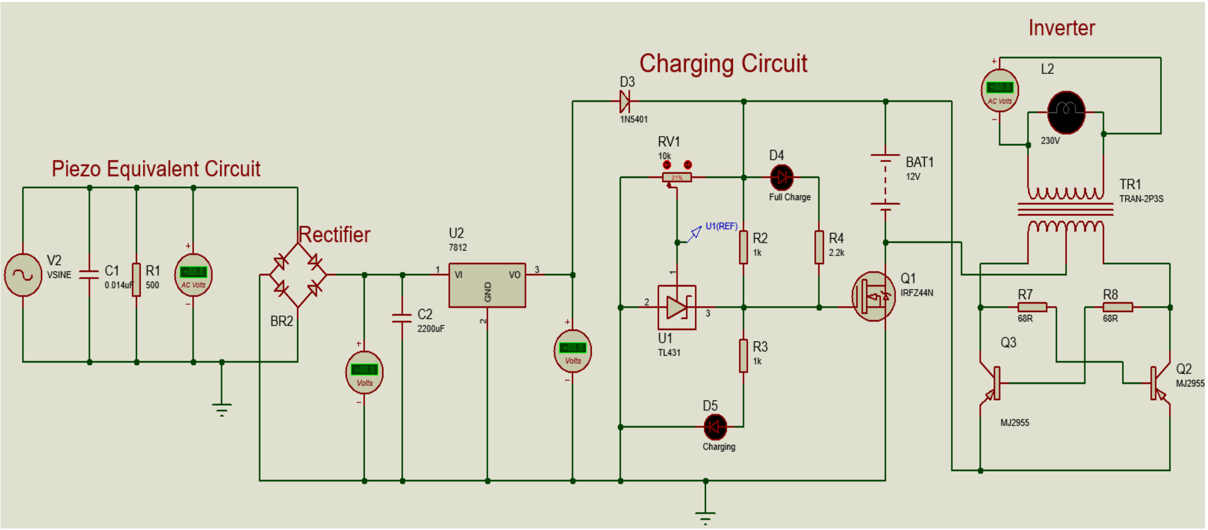


Figure 4.9: Comprised Circuit

4.2.2 Approach 2: Generating Electricity using the deflection of the polyurea-coated cantilever by the turbine

Our project aimed to generate electricity from the deflection of a polyurea-coated cantilever by a turbine. We simulated the system in Matlab Simulink, using a piezoelectric bender to vibrate the cantilever. The vibrations caused the cantilever to deflect and generate an AC voltage. To increase the deflection amplitude, we added a 1000kg mass to the cantilever. The AC voltage was rectified using a full bridge rectifier to convert it into a stable DC voltage, which was then used to charge a 24V battery via a DC-to-DC converter.

Once the battery was charged, we connected a load to the output, and the power was supplied from the battery to the load. To ensure stability and prevent oscillations, we included a damping factor in the circuit. To visualize the generated waveform, we used a scope, which indicated that the charging and discharging of the battery were consistent and stable.

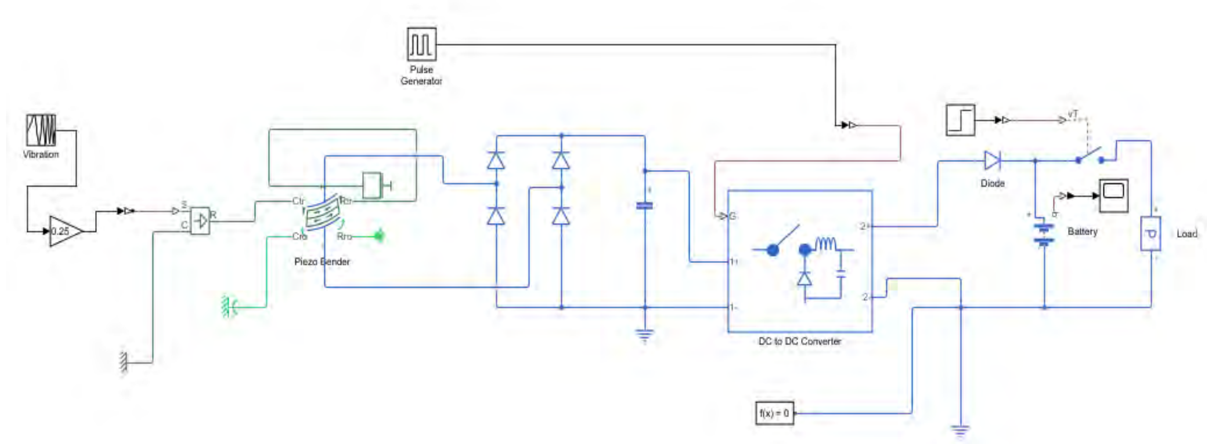


Figure 4.10: Simulation of the deflection of a polyurea-coated cantilever by a turbine.

Our project successfully demonstrated the feasibility of generating electricity from the deflection of a polyurea-coated cantilever by the turbine. This design could harness energy from various sources of vibration and could be useful in applications such as power generation and sensing. By simulating the entire system in Matlab Simulink, we were able to test the system for various parameters and verify that the generated voltage was rectified and stable. The charged battery was used to power a load, showing the practical application of the design. The charging and discharging waveform is given below:

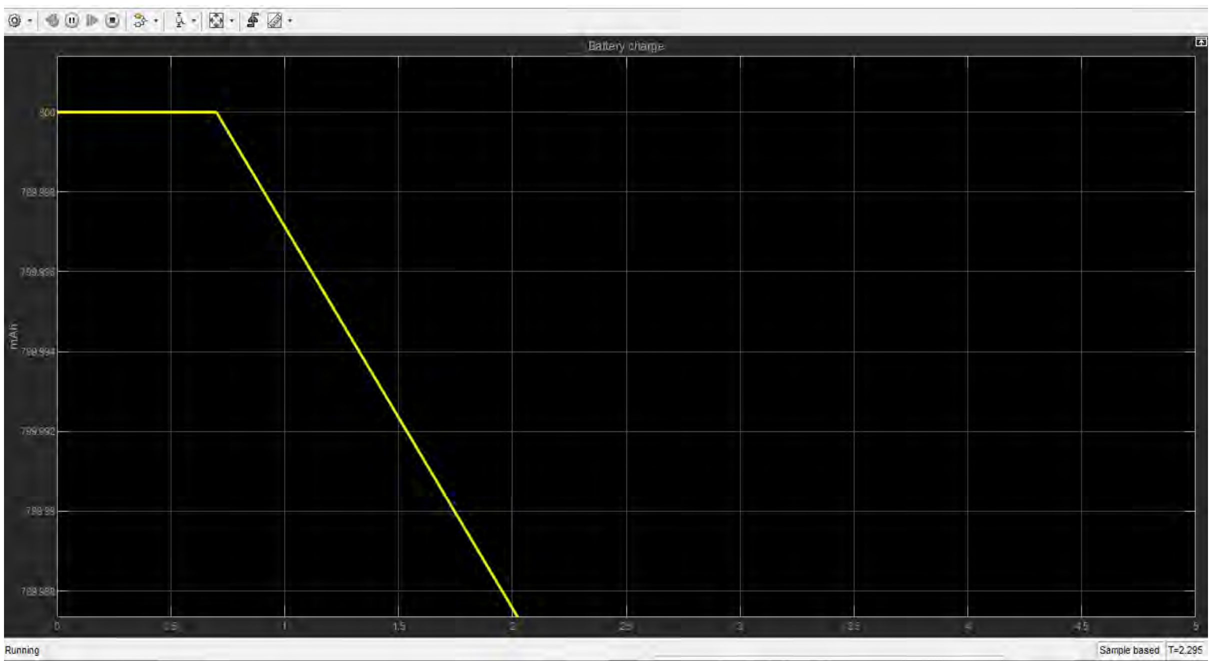


Figure 4.11: Waveform of charging and discharging of a battery.

As seen in the figure below, our original concept calls for coating triangular cantilever beams and mounting them to housing on wind turbines. The study also demonstrates that because longer beams have more deflection, we can create higher voltage with longer cantilever beams. The graph is shown below:

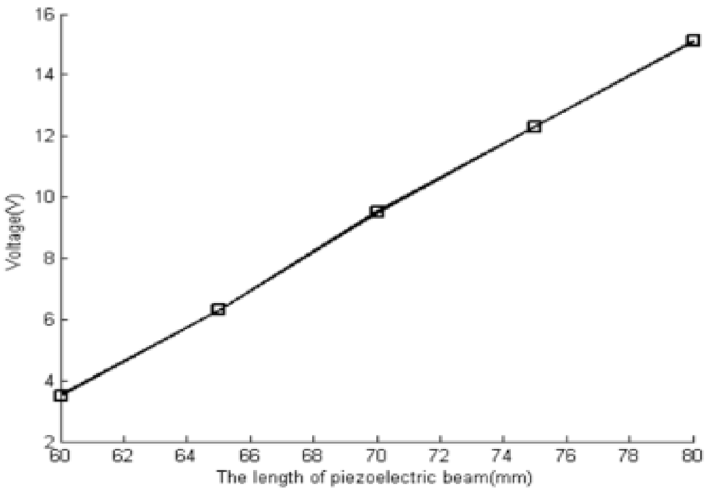


Figure 4.12: Voltage vs length of the beam [30]

4.2.3 Approach 3: Power Generation by Piezoelectric Oceanic Wave Energy Converters (OWECs)

Despite being a reliable source of electricity, we were unable to simulate piezoelectric oceanic wave energy converters (OWECs) using popular programs like Matlab Simulink or Proteus after conducting a literature review. This sets the OWEC's approach apart from other approaches we are pursuing, which may be simulated using these computer programs. Notwithstanding this drawback, the OWECs have demonstrated promise in generating electricity from ocean waves, which is a renewable source of energy. Improvements in the production, effectiveness, and general sustainability of OWECs as a workable energy source in the future may result from additional research and development in this field. Around 2 TW is the projected global OWE potential. Based on the resources that are close to the UK shoreline, the predicted OWE can generate 50 TWh per year, which can meet 14% of the country's overall electrical energy consumption [31]. The estimated extractable OWE in China is around 21.79 GW. The exploitable OWE was estimated by the European World Energy Council and Commission to be between 120 and 190 TWh/year offshore and between 34 and 46 TWh/year for near-shore locations [32], [33]. The following table provides a summary of OWE's potential in Europe based on geographic areas.

Table 4.1: Potential of OWE

Nation	**OWE potential (TWh/year)**	
	Nearshore	Offshore
Germany	0.3–0.5	0.9–1.4
Greece	1–2	4–7
Denmark	2–3	5–8

Italy	3–5	9–16
Spain	3–5	10–16
France	3–5	12–18
Portugal	4–6	12–18
Ireland	7–11	21–32
UK	14–21	43– 64

From the literature review, it is found that it is possible to generate micro-watt power scale electricity from 0.5 m/s wave velocity [34]. The estimated consummate power of an oceanic wave can exceed 50 kW/m of the wavefront. The production of electricity from the kinetic energy of oceanic waves is considered as a promising alternative to meet the global energy demand [35]. The figure shows a floating type oceanic WEC with a piezoelectric bar made of lead zirconate titanate material,

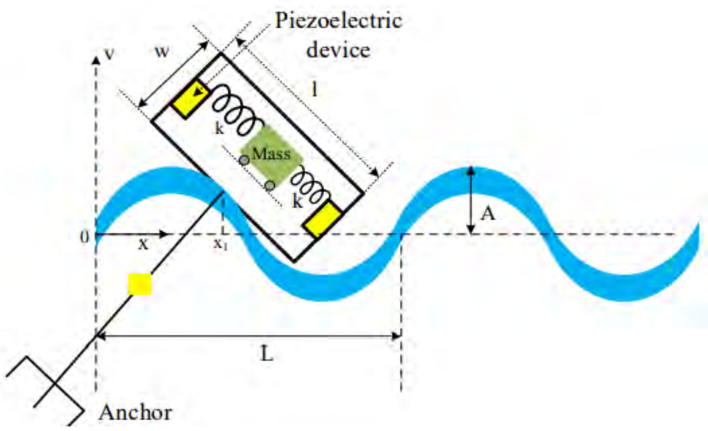


Figure 4.13: Schematic depiction of the flexible energy harvester on sea waves [36].

The position becomes about equal to x1, as shown in Figureure when the entire energy transducer is constrained by the anchor or other form of fixing to maintain the dynamics of the waves. The system associates the connecting rod to connect a floating buoy to the seabed [36]. Now, based on various research papers, it is evident that oceanic wave energy converters (OWECs) have significant potential to be implemented in hardware.

4.3 Identify optimal design approach

4.3.1 Approach 1: Generating Electricity through piezo-electric crystal by Pressure

- Usability: The potential for using pressure to create electricity through piezoelectric crystals is quite promising. The technique can be used in a variety of industries, including transportation, aircraft, and marine energy. Tiny electrical devices, sensors, and actuators can all be powered by it. The piezo disks can also be simply integrated into already-existing buildings, such as ports or bridges, without resulting in any substantial alterations or disturbances. The technology is reasonably simple to comprehend and put into practice because it is based on a straightforward physical occurrence. Also, the fact that it doesn't require an external power source or fuel makes it a practical and affordable option for producing electricity in isolated or difficult-to-reach areas. Because of this, the technology's usability is highly diverse and offers a wide range of potential applications.

- Cost: The cost analysis of the project for generating electricity through piezoelectric crystals by pressure shows that the total cost is 22,792 BDT, with the inverter being the most expensive at 16,500 BDT. This makes the project cost-effective and feasible for implementation. Additionally, the use of piezoelectric crystals does not require any fuel or ongoing maintenance costs, which further adds to its cost-effectiveness and sustainability. Overall, the project offers an affordable solution for generating electricity, making it a viable option for areas where traditional sources of electricity are not available or expensive.
- Efficiency: It has been found that piezoelectric crystals are efficient at converting mechanical pressure into electrical energy. The quality and orientation of the crystal, as well as the intensity and repetition of the applied pressure, all affect how well energy is converted. Piezoelectric crystals typically have conversion efficiencies between 10% and 90%, with some high-end crystals having conversion efficiencies of above 95% [37]. The output voltage and current can be increased by connecting more piezoelectric elements in series or parallel, which will also boost efficiency. However, due to crystal damage or alterations in the environment, piezoelectric generators' effectiveness may degrade over time. Over time, proper system calibration and upkeep can help sustain its effectiveness. Overall, piezoelectric generators have a high potential for efficient conversion of mechanical energy into electrical energy.
- Manufacturing and Maintainability: The manufacturing process involves growing the crystal material to the desired size and shape, followed by cutting and polishing it to the appropriate thickness. The finished gadget is put together after the crystals have been coated with electrodes. It is an environmentally friendly choice because the manufacturing procedure is reasonably simple and doesn't call for any difficult or dangerous materials.

  In terms of maintainability, piezoelectric crystal-based systems are relatively low-maintenance, requiring only periodic cleaning and inspection to ensure optimal performance. Because of its stability and ability to survive extreme climatic conditions, crystal material is excellent for usage in maritime areas. The crystal will need to be replaced, which can be expensive if it is damaged. Overall, piezoelectric crystal-based systems have excellent manufacturing and maintenance characteristics, making them a desirable choice for the production of sustainable energy.

- Impact: Piezoelectric crystal technology is a sustainable way to generate electricity as it doesn't produce any harmful emissions, making it an environmentally friendly option. By implementing piezo disks under a speed breaker into a port, we can generate electricity from the pressure exerted on the disks. This method has minimal impact on the environment and ecology as it does not require any fuel or produce any pollutants or waste The use of piezoelectric crystals can help reduce the carbon footprint and dependence on non-renewable sources of energy, contributing to a cleaner and greener environment.

- Sustainability: Piezoelectric crystals have been demonstrated to be a dependable and long-lasting energy source. We can efficiently capture the energy produced by the passing waves by incorporating piezo disks under a speed breaker into a port. With the right care, piezoelectric crystals can live up to 20 years and continue to produce electricity during that time [37]. Moreover, piezoelectric crystals are an environmentally friendly choice for producing electricity because they don't emit any toxic gases. A promising strategy for creating sustainable energy is the use of piezoelectric crystals to create electricity under pressure. It is a sustainable alternative for the future because it has the ability to offer a constant source of clean energy without endangering the environment or depleting natural resources.

4.3.2 Approach 2: Generating Electricity using the deflection of the polyurea-coated cantilever by the turbine

- Usability: The initial setup of the system is a bit of a long process since it involves several rotating/moving parts and the integration between all components. But it can be reliable and sturdy in extreme port conditions when set up correctly. Although accumulation of dust with humid salty port air may affect performance, a separate study is required to observe performance losses, but initial observation points towards little loss when used following proper procedures

- Cost: From our cost calculation, we find this setup to be expensive. But to generate power the cost may go more high and applying multiple of these are budget exhaustive. The most expensive parts of the wind turbines are also quality-sensitive. We may lose performance if the proper quality is not maintained when sourcing these parts.

- Efficiency: The average efficiency of our system can be calculated from future applications of the system in the real world because only then authentic data may be collected and put to rigorous research and development to find optimum performance

- Manufacturing and Maintainability: Specialized manufacturing is required to make the turbines and housing for the system, and to set up the system, many modifications may be required since such technology is new for our country. Besides while setting up the system precautions must be taken not to hamper port operations

- Impact: This system will have a positive impact on gaining desired results when set up properly, But it is an exclusive and skilled job so trained individuals are required for this system. Also, it is to be noted that our system is designed to be environment friendly and energy saving. So we expect that when implemented there will be positive changes and will bear impactful results towards more secured port operations

- Sustainability: With proper process and maintenance, the system will be sustainable but it also requires further study in real-world scenarios. Our initial concept points towards this setup being maintenance intensive

4.3.3 Approach 3: Power Generation by Piezoelectric Oceanic Wave Energy Converters (OWECs)

- Usability: For the generation of electricity from ocean waves, piezoelectric oceanic wave energy converters (OWECs) are a promising technology. The method transforms the kinetic work of ocean waves into electrical energy by using the piezoelectric effect. OWECs have the ability to offer a clean, renewable energy source with little harm to the environment. The technology is scalable and can be used in various applications, including offshore power generation, remote monitoring, and oceanographic research.

- Cost: Even though there are benefits to using piezoelectric Oceanic Wave Energy Converters (OWECs) to harness power from ocean waves, the technology is more costly than alternative approaches. The cost of the system as a whole, with inverters and linear generators included, comes to about 45,942 BDT, with the latter being the most costly part at 22,000 BDT. The use of OWECs as a renewable energy source may have a greater initial cost, but the long-term advantages may exceed the disadvantages, making it a workable option for the generation of sustainable energy.

- Efficiency: A review of the literature indicates that piezoelectric Oceanic Wave Energy Converters (OWECs) power generation has demonstrated promising efficiency. The design of the system, the qualities of the materials, and the operating circumstances are only a few of the variables that affect how well OWECs convert energy. According to reports, OWECs' efficiencies can range from 5% to 25%, which puts them on par with existing wave energy conversion technologies. [38] By refining the system's architecture and using the right materials for the piezoelectric components, OWECs can increase their efficiency. The system's efficiency may be greatly increased by using high-quality piezoelectric materials with excellent sensitivity and stability. By increasing the system's power production, improved control algorithms can further increase the effectiveness of OWECs.

- Manufacturing and Maintainability: Piezoelectric Oceanic Wave Energy Converters (OWECs) are manufactured using specialized technologies and materials. Making the piezoelectric transducers, which transform the mechanical energy of the ocean waves into electrical energy, is a step in the process. The power conditioning unit, which transforms electrical energy into usable power, is one of the components the transducers are combined with after that. The manufacturing process is intricate and demands knowledgeable workers and specialized tools, which might raise the system's overall cost.

In terms of maintainability, OWECs require periodic inspection and maintenance to ensure their optimal performance. The effectiveness of the transducers may be impacted by a variety of environmental variables, such as corrosion, fouling, and mechanical damage. Cleaning, replacing broken components, and inspecting the electrical systems are all examples of maintenance tasks. Due to the severe surroundings, maintenance tasks for OWECs placed in maritime locations might be difficult. Hence, to minimize downtime and guarantee their long-term sustainability, the design of OWECs must take ease of access and maintenance into account. In order to achieve the best performance and longevity of OWECs, great thought must be given to their manufacturing and maintainability.

- Impact: (OWECs) have the potential to significantly influence the renewable energy sector by offering a reliable supply of green energy. Using OWECs can lessen reliance on fossil fuels, lowering greenhouse gas emissions and lessening the impact of climate change. In isolated areas and on islands where access to energy is scarce or nonexistent, OWECs can provide offer a dependable supply of electricity. Also, the usage of OWECs may open up employment prospects in the design and installation of the equipment. OWECs are a potential technology for the future since they may generally have a good influence on the environment, society, and economy.
- Sustainability: Piezoelectric Oceanic Wave Energy Converters (OWECs), which exclusively rely on the natural motion of ocean waves, provide a sustainable method of energy generation. This indicates that they provide clean, renewable energy, reducing our reliance on fossil fuels and greenhouse gas emissions. Also, because they don't emit any pollutants or endanger marine life, OWECs have a negligible influence on the environment. Additionally, as OWEC technology advances, the production procedures become more environmentally friendly. The gadgets' components may be recycled, and they can be made to be simple to disassemble and repair. OWECs have a long lifespan and can provide clean energy for many years to come with proper maintenance. Therefore, the sustainability of OWECs makes them a promising technology for a cleaner and more sustainable future.

4.3.4 Design Comparison

Table 4.2: Design comparison

Basis	Piezo-electric crystal by Pressure	Deflection of the polyurea-coated cantilever	Oceanic Wave Energy Converters (OWECs)
Precision	High	Low	Low
Power Loss	Minimum	Moderate	Maximum
Longevity	Minimum 12 years	Less than others	About 5 to 6 years
Building cost	Appox. 23,000taka	Approx.53,000 taka	Approx.46,000taka

From the comparison table, we can see that the longevity of Approach 1: piezo-electric crystal by pressure is greater than that of other approaches. As it is based on pressure, the building cost is also lower than the other two approaches. On the other hand, approach 2: deflection of the polyurea-coated cantilever, has a higher building cost because it will have a wind turbine, which costs more. After observing the comparison, we can say that approach 1 will be the optimal solution for our project.

4.3.5 Design Approach Advantage and Disadvantages

Table 4.3: Advantages and disadvantages of the approaches.

Approaches	Advantage	Disadvantage	Cost (BDTK)
Piezo-electric crystal by Pressure	1. Longeability 2. More Efficiency 3. Durable	1. Too much precision requires	22,792
Deflection of the polyurea-coated cantilever	1. Both windmill and piezo energy	1. High Cost 2. Less Efficiency	52,603
Oceanic Wave Energy Converters (OWECs)	1. Continuous Power	1. Power Loss 2. Less longeability	45,942

Considering all the attributes and cases we found that our Approach 1 is the optimal solution.

- Since the approach 1 has more advantages compared to other approaches. In the comparison table, we can see that the precision of approach 1 is compared to others. In the case of approach 3 the biggest disadvantage is that it will have a huge power loss since the system needs to be implemented in the sea. As we know power losses occur in the transmission line. On the other hand, approach 1 will be implemented beneath the speed breaker and thus it will be close to the load. So, there will be no issue of power loss in Approach 1. In the case of Approach 2, the cost of building is too high.

Moreover, to implement this first we have to build a mill in the port area, which might be a hamper to the port operations. The proposed budget for large-scale integration was initially higher, our prototype's actual cost is significantly lower than originally anticipated. This cost-saving development is a positive outcome for our project.

So, comparing all the cases of the three approaches, we found that Approach 1 will be the best optimal solution to build as it will be highly efficient.

4.4 Performance evaluation of developed solution

The circuit Diagram of our optimal approach is again shown below,

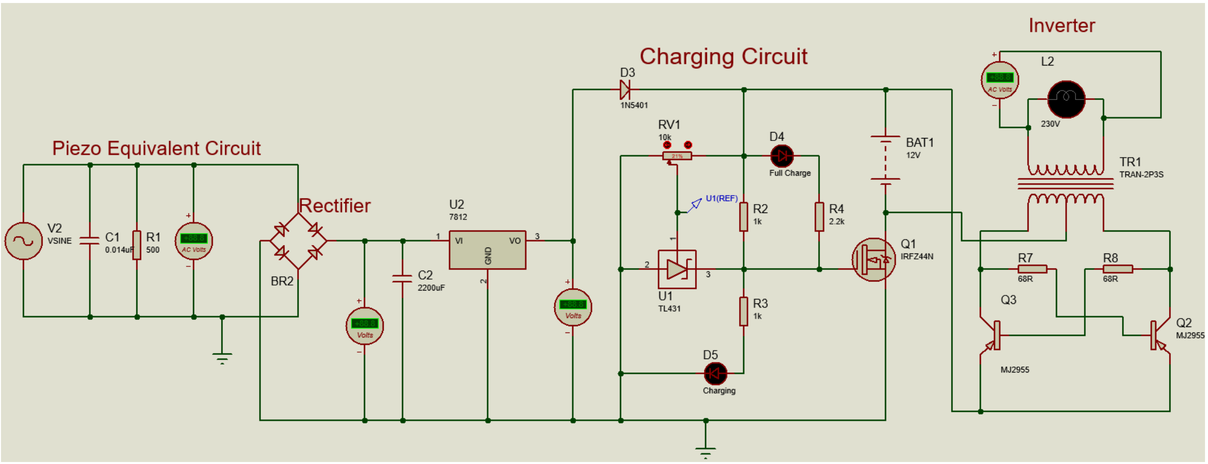


Figure 4.14: Comprised Circuit

<u>Test Case 1</u>:

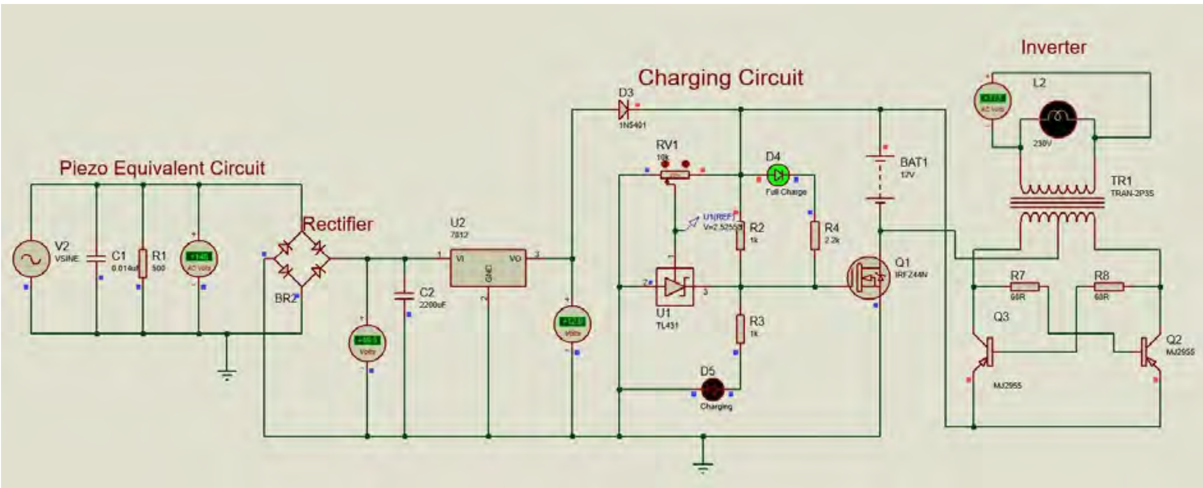


Figure 4.15: Test Case of Comprised circuit

Here, when we run the simulation we can see that the full charge LED is glowing. It means that the battery is fully charged and able to run the load. So, the load lamp is glowing.

Test Case 2:

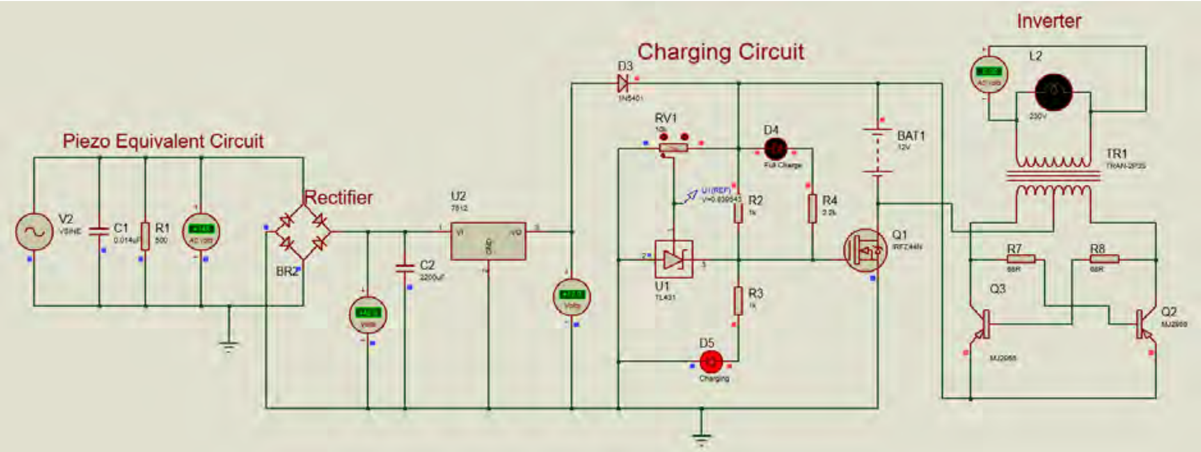


Figure 4.16: Test Case 2 of Comprised Circuit

Here, in the second test case, we can see that the lamp is not glowing. It's because the battery is charged that we can see that the red LED is glowing. While the battery is charging, the load will not be powered up.

We will evaluate the integrated circuit designed for piezoelectric energy harvesting in terms of its performance and efficiency. The Proteus simulation surroundings, which were described previously in 4.3, formed the basis for all of the test cases used in this. The following criteria have been considered while assessing performance:

- Efficiency in Charging: Our system's primary objective is to properly charge a battery with piezoelectric energy. The blinking full charge LED in Test Case 1 showed that the battery had been successfully charged.
- Powering a Load: Test Case 1 demonstrated that, after being fully charged, the battery could power a load (represented by the glowing bulb). This shows how the electricity generated may be used in everyday life and how it can power various additional devices.
- Voltage Regulation: We integrated a voltage regulator into the circuit to ensure a constant and steady voltage output. The regulator's performance will be determined by its ability to it manages to maintain a constant voltage level in spite of the inherent instability of piezoelectrically generated AC voltage.
- Battery Management: In order to regulate how the battery is charged, the charging circuit is included. We will evaluate the impact it has on keeping the battery healthy by avoiding overcharging or other unsafe conditions.
- Versatility: The system's adaptability will be evaluated by evaluating how well it performs under different situations, such as changes in mechanical load or vibrations. This will help in determining how well the system will cope with real-life scenarios.

- Reliability: Test Case 2 showed a situation in which the battery was charging and the load was unable to be powered. To ensure reliable performance, the system's dependability in both charging and discharging states will be checked.
- Energy Loss: Any energy losses that occur during the energy conversion process will also be considered. This covers any potential inefficiencies, such as losses in the rectifier, regulator, and inverter.

By assessing the above aspects of the developed solution, we want to obtain a thorough understanding of its functioning and spot any potential areas for development or optimization.

4.5 Conclusion

In this chapter, the objective is to find the most effective method of generating power with piezoelectric materials. The project's viability would depend on choosing the best approach among the design methods, according to the fundamental concept. The potential of approach 1 has been clearly shown by Proteus simulations. A piezoelectric disk calculator has been added to improve the process of determining the necessary elements based on user input data, making it easier to choose the piezoelectric disk count. The use of full-wave rectifiers and charging circuits assisted in describing the step-by-step power generation process. In Approach 2, we found a cutting-edge method for harnessing vibrational energy. We tested the validity of this method using simulation in Matlab Simulink, which offered a reliable platform for testing. We verified the stability of the generated voltage during these simulations, emphasizing the application of this concept. Moreover, there were particular constraints with Approach 3. We had to rely on data from research papers in the lack of software for simulation to fully understand its potential.

The result of our work was the comparison table, which highlighted the advantages and disadvantages of each strategy. The most effective approach is Approach 1, which stands out for its durability and efficiency. It became the best alternative because of the strategic proximity to the load, which reduced power losses. In contrast, Approach 3 met major challenges, mostly as a result of worries about power loss caused by its use in the ocean. Although, Approach 2 required the installation of wind turbines, that increased building costs. Our thorough analysis, which considered a number of factors and potential outcomes, convinced us that Approach 1 is the best course of action. This decision is completely compatible with our ultimate goal, which is to effectively utilize green energy and contribute to a future that is more environmentally conscious.

Chapter 5: Completion of Final Design and Validation [CO8]

5.1 Introduction

In the previous chapter, we analyzed our three approaches based on different perspectives and found our optimal design to make a prototype. Our optimal design is the first approach, which is generating electricity through piezo-electric crystal by pressure. Based on the simulation of the first approach, we went through the online markets to find the best components according to our required specifications. The first approach was to generate electricity by using the pressure exerted by the vehicles on the speed breaker. The proposed system uses the piezoelectric effect to generate AC voltage when pressure is applied to a piezoelectric device. Subsequently, the generated AC voltage is rectified to DC voltage using a rectifier circuit. Furthermore, a DC-DC buck converter is integrated into the system to step down the voltage and efficiently store the harvested energy in a rechargeable battery. In the final stage of the system, an inverter is utilized to convert the stored DC voltage back into AC, enabling the power supply of the surveillance system. Now we will have a complete overview of making the prototype.

5.2 Completion of final design

5.2.1 Component Details:

- Piezo disk: A 35mm piezo disk is a small, circular piezoelectric component measuring 35 millimeters (about 1.38 inches) in diameter. They are made of piezoelectric materials, such as quartz or ceramics. Piezo disks are used to transform mechanical energy (pressure or vibration) into electrical energy. They generate a voltage when subjected to mechanical stress, and this voltage can be used for various applications, including sensing, actuation, and energy harvesting. For our design, we used 60 piezo disks.

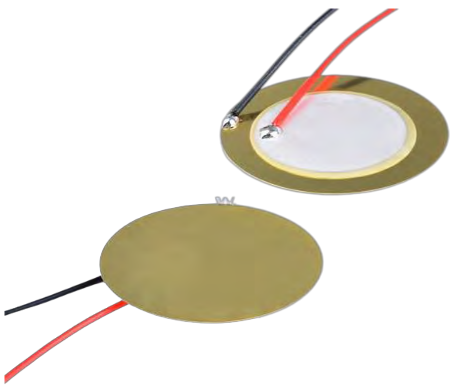


Figure 5.1: Piezoelectric disk

- Rectifier: The 2W10 rectifier is a compact electronic component designed for converting alternating current (AC) into direct current (DC) in electronic circuits. It is ideal for low to moderate power applications because it has a maximum forward current rating of 2 amps and a peak reverse voltage capacity of 1000 volts (1 kilovolt) [39]. There are 4 pins in the 2W10 rectifier. The two pins marked with (~) are for the AC inputs. The positive (+) and negative (-) marked pins are for the DC outputs. The 2W10 rectifier serves as an essential component in a variety of electronic devices, power supplies, and battery chargers, ensuring a stable and effective source of DC voltage for their appropriate operation. It has a glass passivated design for improved performance and dependability. For our design, we used six 2W10 rectifiers.

- Diode: The 1N4007 diode is a common semiconductor device with two pins labeled as the cathode (K) and anode (A). The fundamental function of the 1N4007 diode is to enable electrical current to pass in one direction (from the anode to the cathode) while blocking it in the opposite direction. The 1N4007 diode is appropriate for a variety of applications where voltage and current conversion are crucial since it has a high peak reverse voltage (usually 1000 volts) and can handle reasonably high current levels.

- Capacitor: An electronic component called a capacitor is made to store and release electrical energy. It comprises two conducting plates separated by a dielectric, an insulating substance. Capacitors are distinguished by their capacitance, which is measured in farads (F) and indicates their ability to store charge. Other parameters include tolerance (precision of capacitance value), voltage rating (maximum voltage the capacitor may safely take), and form factor (size and shape). In our design, we used six capacitors of 47μF 50V and one capacitor of 2.2 μF 50V.

- Buck Converter: A DC-DC Buck converter is an integrated circuit (IC) that steps down or reduces a higher input voltage to a lower, more regulated output voltage. We used an LM2596 DC-DC buck converter whose input voltage range is 3-40V and the output voltage range is 1.5-35V which can be adjusted by a built-in potentiometer.

- Battery: A 12V lead-acid battery is a common type of rechargeable battery widely used in various applications. This battery is designed to provide a stable 12-volt direct current (DC) output and is characterized by its lead dioxide (PbO_2) positive plate, sponge lead (Pb) negative plate, and a sulfuric acid (H_2SO_4) electrolyte solution [40]. It stores electrical energy through chemical reactions that occur when it's charged and discharged.

  Lead-acid batteries are known for their reliability, affordability, and ability to deliver high current. However, they are relatively heavy and have a lower energy density compared to some other battery technologies. Regular maintenance, such as topping up electrolyte levels with distilled water and ensuring proper ventilation, is necessary to prolong their lifespan. Despite advancements in battery technology, lead-acid batteries remain a staple choice for many applications due to their well-established performance and cost-effectiveness, especially when a consistent 12-volt power source is required. The specification of the battery that we used is shown in the table below:

Table 5.1: Specification of the battery

Constant Voltage Charge at 25°C	**Voltage regulation**	**Initial Current**
Standby use	13.62V-13.8V	1.875A
Cycle use	14.1V-14.4V	1.875A

- Inverter: A 500-watt inverter is an electronic device designed to convert direct current (DC) power, typically from a battery or a solar panel, into alternating current (AC) power at a rated output of 500 watts. We selected this 500-watt inverter because it is the lowest-rating inverter that is found in the current market.
- Voltage Display: We used a display that shows how much DC voltage is generated when a vehicle passes over the speed breaker.

5.2.2 3D Design

To make a prototype of our design we had to keep a lot of things in mind. So, to make the prototype more precise we made a 3D design. Here is the 3D design:

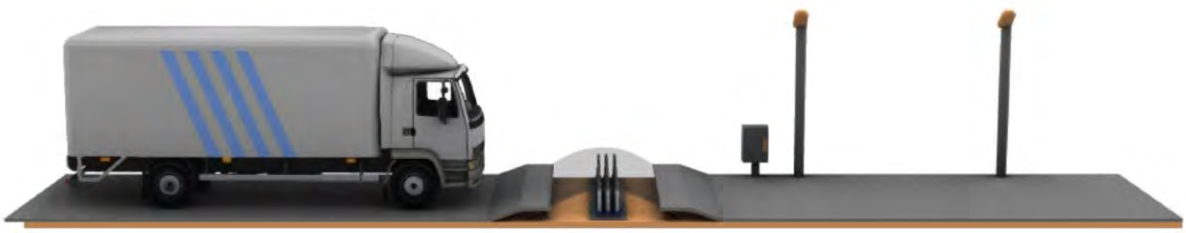


Figure 5.2: 3D design 1

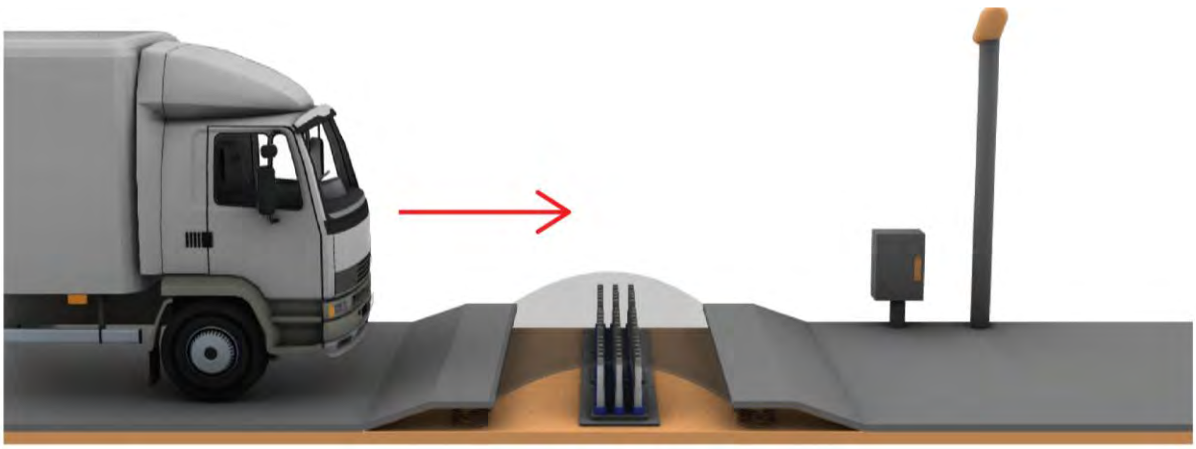


Figure 5.3: 3D design 2

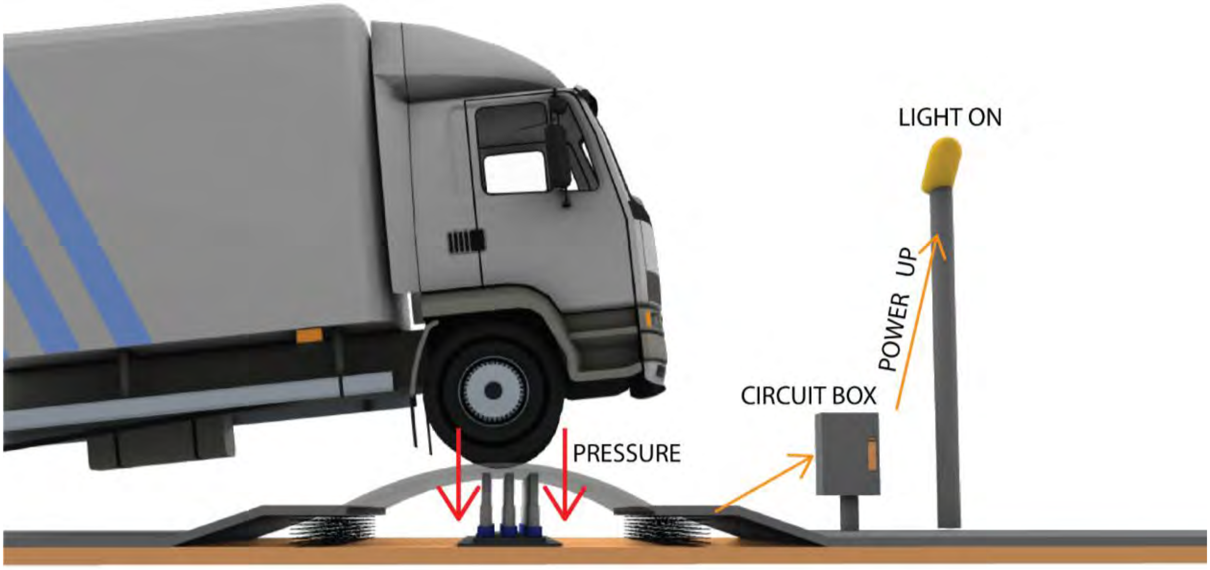


Figure 5.4: 3D design 3

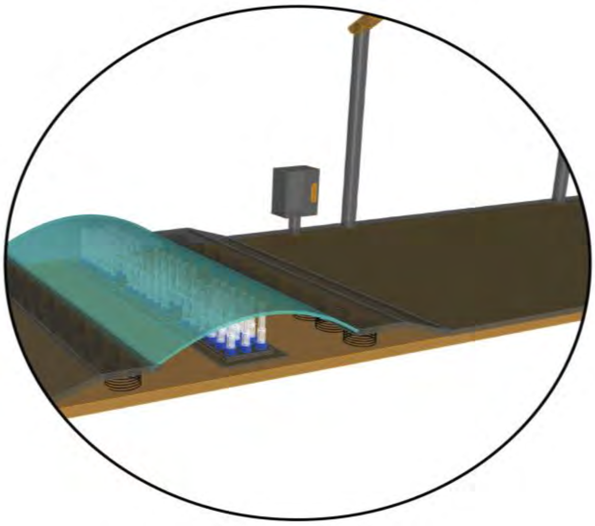


Figure 5.5: 3D design 4

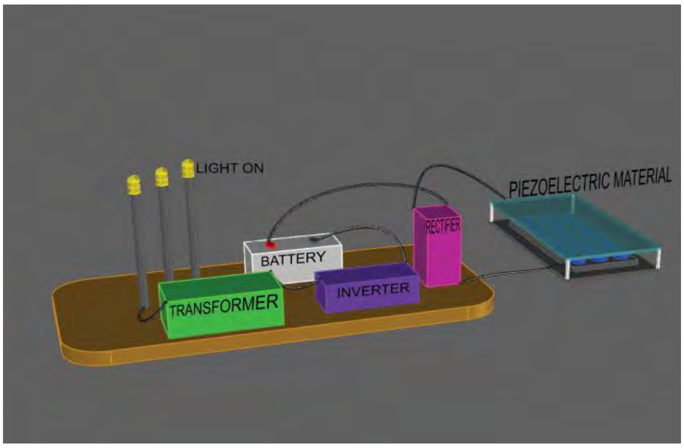


Figure 5.6: 3D design 5

The above figures are the 3D view of our design and where we will implement our design. Figure 5.2 is the overall view of the place where we will implement the circuit. It will be in the speed breaker of the entrance gate. Figure 5.3 shows the movement of the truck and its approach toward the speed breaker. The figure 5.4 is when the truck is over the speed breaker. While the truck is over the speed breaker the pressure from the truck will be exerted on the piezo and the piezo will convert this mechanical energy into electrical energy and will charge the battery. In the figure 5.5 it is shown that we placed the piezo plates beneath the speed breaker. Since there is a gap between the piezo and the speed breaker we used some rubber pipe so that the pressure is exerted on the piezo. Moreover, we used a spring between the speed breaker surface and the road so that the speed breaker comes to its original position after it goes down due to the pressure of the truck. Figure 5.6 is just a sample 3D view of the circuits.

So, we can see that when the truck goes on the speed breaker, a huge amount of pressure is applied to the piezoelectric material, and in this way, we can generate electricity for the surveillance system of the port area.

5.2.3 Circuit

As we discussed earlier for a better output voltage and current, we need to arrange the piezo disks in parallel or in series. If we connect the piezo disks in series it will multiply the voltage and if we connect the piezo disks in parallel it will multiply the current. So at first, we connected five piezo disks in series which makes a piezo array. After that, two such series-connected piezo arrays are connected in parallel to form a stack of piezo arrays. Such six piezo stacks are made. The six piezo stacks are demonstrated in the given figure

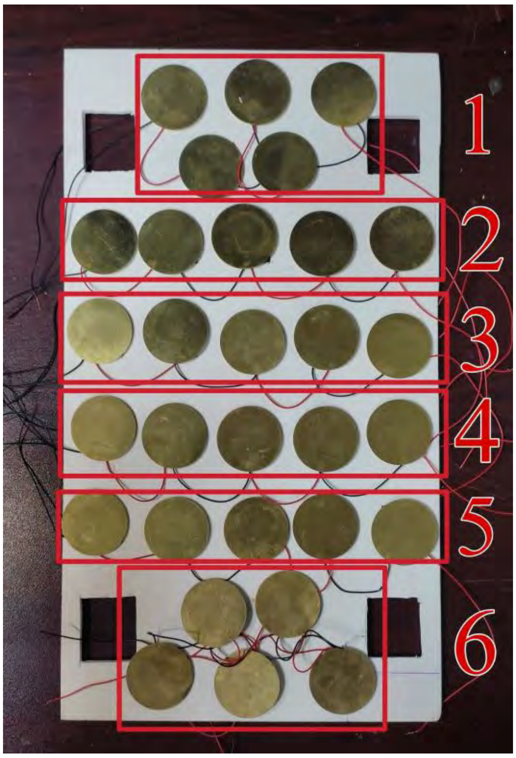
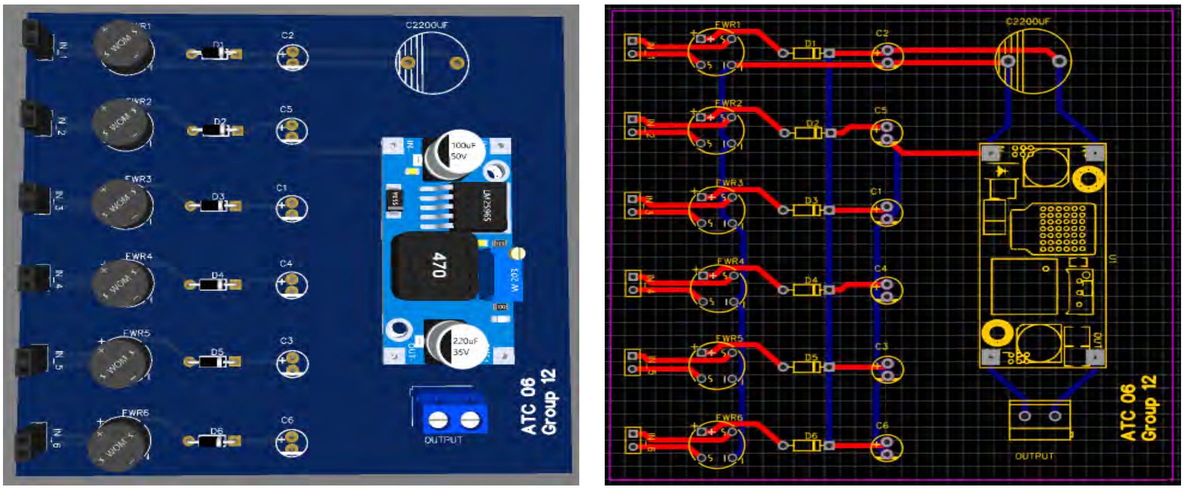


Figure 5.7: Piezo Stack

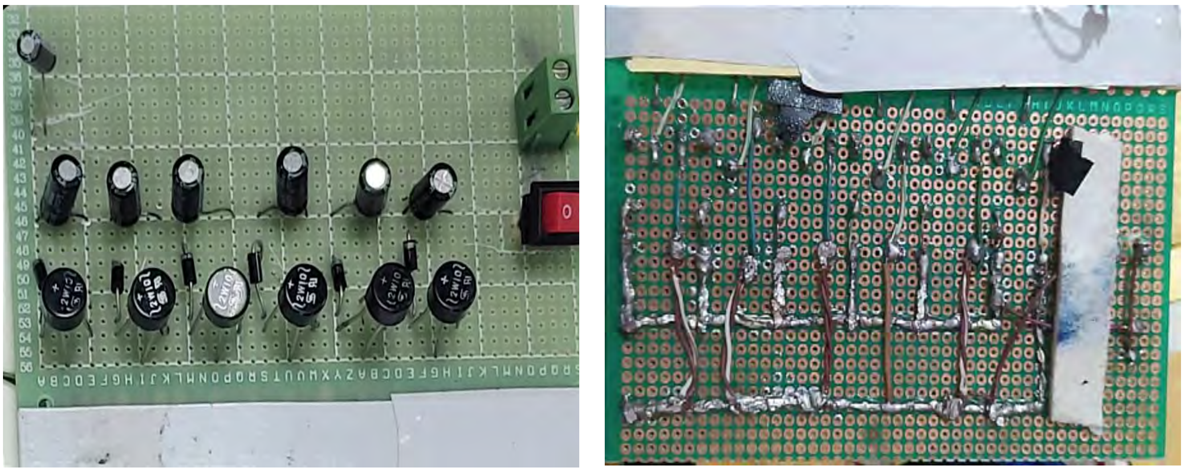
For developing the circuit, we designed a printed circuit board (PCB). However, we could not do our final circuit on the PCB because it got short-circuited twice. Here is the PCB design of our circuit board.



(a) (b)

Figure 5.8: (a) 3D view of the PCB (b) PCB layout

When the PCB got short-circuited twice after that we used a vero board to make our circuit. Here is the final circuit



(a) (b)

Figure 5.9: (a) Upper view of circuit board (b)Lower side view of circuit board

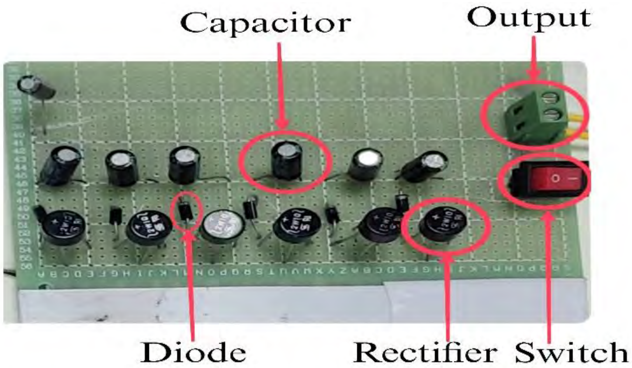


Figure 5.10: Detailed Circuit board

Here in Figure 5.10 we can see the components we used in the circuit. The six 2W10 rectifiers are used for the six stacks of piezo to convert AC voltage into DC voltage. In the input pins of the rectifiers, we connected the positive and negative outputs of the piezo stacks. After that, we connected a diode with the positive (+) output pin of the rectifier so that the piezo doesn't work in reverse effect. Following that we used a capacitor for each stack to filter the noises of the piezo. Finally, the outputs of three capacitors are connected in parallel, while the outputs of the other three capacitors are similarly connected in parallel. Subsequently, these two sets of parallel-connected capacitors are connected in series. In Figure 5.7 we can see that the piezo stacks are numbered. We connected the 1st, 2nd, and 3rd piezo stacks parallelly, and similarly 4th, 5th, and 6th piezo stacks are connected in parallel. Subsequently, these two sets of parallel-connected capacitors are connected in series. After that, we used a capacitor for further filtration. Moreover, we used a switch for the circuit so that if we do not want to generate electricity we can switch off the whole circuit. The final connection of the piezo stacks and the circuit is shown below:

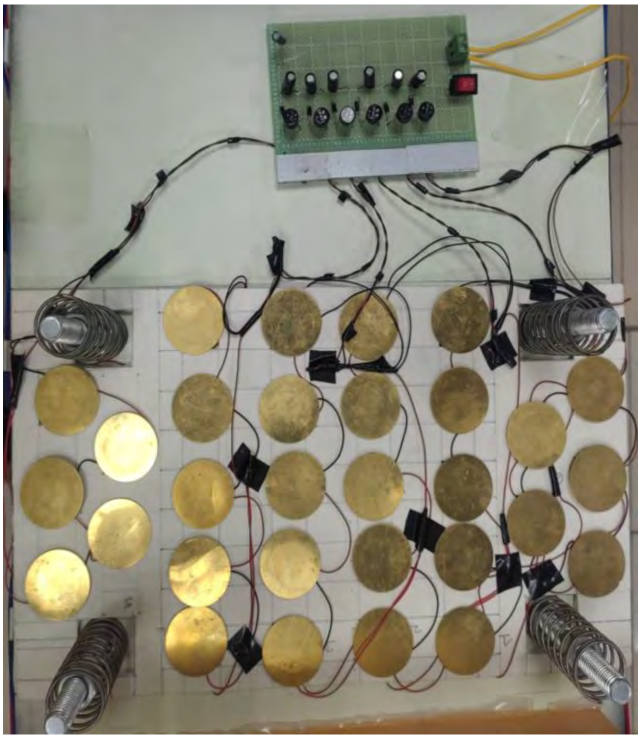


Figure 5.11: Constructed Circuit

Following that we connected the battery with the output terminal of the circuit. In addition, we also connected the voltage display to the output of the circuit to see how much voltage is generated from the piezoelectric material. After that, we connected the inverter with the battery to convert the DC voltage into AC voltage. We also used a switch for the lights. For the prototype, we connected four 5-watt lights and one camera for showcasing. The prototype is shown below:

Figure 5.12: Prototype

5.2.4 Structural Design

The hardest part of making the prototype was to make the structural design of the speed breakers. To make the speed breaker functional as well as to look like the 3D design we had to do a lot of calculations. In figure 5.13 it is shown that we placed the piezo plates beneath the speed breaker. Since there is a gap between the piezo and the speed breaker we used some rubber pipe so that the pressure is exerted on the piezo. Moreover, we used four springs on four corners between the speed breaker surface and the road so that the speed breaker comes to its original position after it goes down due to the pressure of the truck. We also used a nut so that when the speed breaker goes down it does not go down after a threshold height. The structural design is demonstrated next page:

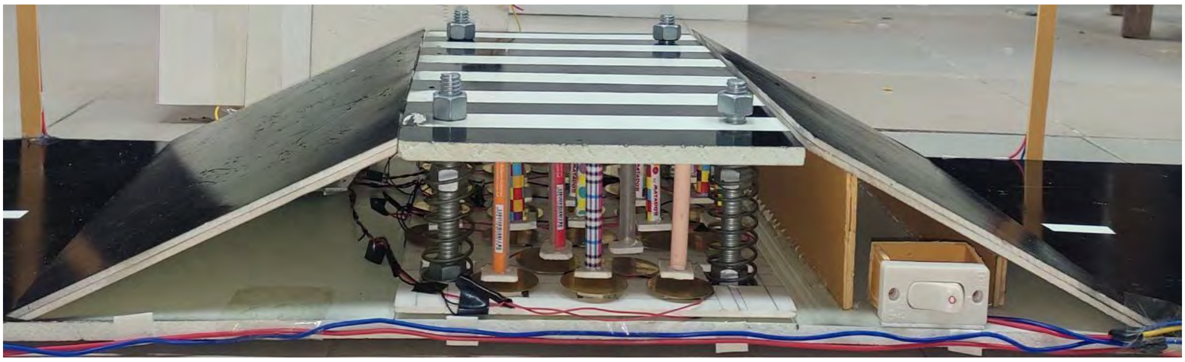


Figure 5.13: Structural Design

5.3 Evaluate the solution to meet desired needs

To meet our desired needs, we conducted experiments numerous times.

Table 5.2: Experimental data of single piezo

Oscilloscope Reading			
	AC	DC	After filtration
Peak-Peak	7.1 V	9.3 mV	97 mV
R.M.S	2.7 V	5.74 V	2.79 V

Multimeter Reading		
AC	DC	After filtration
3.6 V	6.8 V	4.2 V

Table 5.3: Experimental data of five series connected piezo (one piezo array)

Oscilloscope Reading			
	AC	DC	After filtration
Peak-Peak	30.45 V	44.26 mV	97 mV
R.M.S	11.6 V	24.4 V	10.62 V

Multimeter Reading		
AC	DC	After filtration
15.6	29.8 V	18.4 V

Table 5.4: Experimental data of ten series connected piezo

Oscilloscope Reading			
	AC	DC	After filtration
Peak-Peak	57.8 V	80.75 mV	187 mV
R.M.S	21.1 V	45.4 V	19.4 V

Multimeter Reading		
AC	DC	After filtration
27.8	55.7 V	33.4 V

Table 5.5: Experimental data of one piezo stack (two parallel connected piezo array)

Oscilloscope Reading			
	AC	DC	After filtration
Peak-Peak	29.8 V	43.7 mV	95 mV
R.M.S	11.2 V	23.6 V	10.3 V

Multimeter Reading		
AC	DC	After filtration
14.7	26.8 V	16.8 V

Table 5.6: Experimental data of one piezo set (three parallel connected piezo stack)

Oscilloscope Reading			
	AC	DC	After filtration
Peak-Peak	28.7 V	43.5 mV	90 mV
R.M.S	10.9 V	23.4 V	10.1 V

Multimeter reading		
AC	DC	After filtration
14.2	25.7 V	16.1 V

Table 5.7: Experimental data of two series connected piezo set.

Oscilloscope Reading			
	AC	DC	After filtration
Peak-Peak	52.8 V	85 mV	176 mV

Multimeter reading		
AC	DC	After filtration
28.1	49.6 V	31.3 V

R.M.S	21.3 V	45.7 V	19.7 V

In this way examined the output of each step by using oscilloscope and multimeter. Yet, these values won't be constant in every case. The reason behind this is that every time the pressure is not exerted equally or distributively.

Table 5.8: Charging and discharging rate

Charging		Discharging	
Time (min)	Voltage (V)	Time (min)	Voltage (V)
0.16	4.35	0	15
0.42	11.43	2.04	13
0.5	13.61	2.38	12
0.58	15.79	6.5	9

Here, we observed the charging rate of the final capacitor we used as well as the discharging rate of that capacitor to charge the battery. From this observation data we generated a graph;

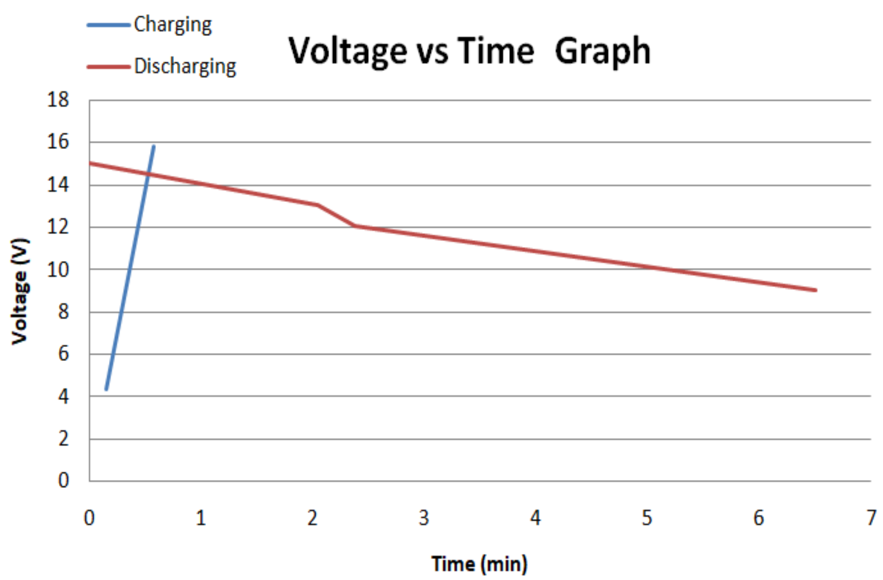


Figure 5.14: Charging and discharging graph

5.4 Conclusion

In this Chapter, we made the essential transition from theoretical analysis to practical operation by starting the process of turning our design concept into a working prototype.

Our system's components are carefully chosen for a particular part of the power generation procedure. Our main electricity conversion devices, the piezo disks, have been organized into arrays to maximize voltage and current output. We fully utilized piezoelectricity by connecting these arrays in series and parallel layouts. A printed circuit board (PCB) created to manage the complexity of our system allowed for this complex setup. Rectifiers, an essential part of our circuit, were essential in converting the AC power generated by the piezo arrays into a constant DC voltage. Diodes were placed carefully in the circuit to avoid reverse effects. The efficiency of the system was enhanced by the addition of capacitors to filter out unwanted noise produced by the piezo arrays. It was possible to store energy efficiently due to the parallel and series coupling of capacitors. We had the ability to stop the electricity generation when it's necessary by including a switch in the circuit design. It took careful thought, problem-solving, and an in-depth knowledge of the principles behind piezoelectricity for us to complete the final design. With component and circuit assembly, a reliable prototype ready for validation was produced.

This chapter described the transition from theory to implementation and showed our commitment to utilizing cutting-edge methods to harness green energy. The prototype represents our drive to transform the world's energy scene for the better, one piezoelectric crystal at a time, and indicates more than just something that exists.

Chapter 6: Impact Analysis and Project Sustainability [CO3, CO4]

6.1 Introduction

Our chosen approach, which involves using piezoelectric material to create power at the port's entrance, is a progressive approach with the potential to have an impact on numerous aspects of society. We look to ensure a thorough impact analysis that considers the overall consequences and advantages of our innovative system that converts mechanical stress into electrical energy when vehicles pass over the strategically placed piezo disks.

It is crucial to understand the full significance of this technology. The installation of piezoelectric devices could have a range of effects. Since it generates a good amount of electricity, especially in high-traffic port areas, it primarily promises a significant reduction in the carbon footprint associated with conventional energy sources. The social, environmental, and financial effects of this shift are explored in depth in this paper. It looks at how this program can improve energy efficiency, have a beneficial impact on the surrounding area, and help achieve the world's sustainability targets.

One of the main principles of this accomplishment is project sustainability. Beyond the initial deployment, the system's longevity is essential. The project encourages sustainability by minimizing reliance on conventional power sources and integrating with greener energy options. In addition, the project's sustainability in the future depends significantly on safety, legal observance, and respect for regional cultural values. This introduction emphasizes the comprehensive strategy used to assess and ensure the long-term effects and sustainability of the installation of the piezoelectric device in the port area.

6.2 Assess the impact of the solution

The impact of our design regarding societal, health, safety, legal, and cultural concerns is reviewed below

6.2.1 Societal Impact

The installation of piezoelectric devices beneath the speed breaker at the port entrance benefits society in addition to providing a source of renewable energy [41]. Our approach helps in supplying the port with at least a small quantity of additional power because ports need a substantial amount of electricity to operate continuously. This extra power source can help decrease the need for non-renewable energy sources and promote environmental cleanliness. Also, the use of this technology in ports may encourage other sectors to switch to renewable energy sources, which might have a significant effect on society. It can foster innovation, open up new job possibilities, and raise public awareness of the advantages of adopting renewable energy sources.

Piezoelectric devices can be installed beneath speed breakers at port entrances, which offers a flexible option that not only supplies a renewable energy source but also has a number of positive social effects. Ports are busy economic centers that require a steady and ample supply of electricity to enable operations around the clock. We can add an additional power source to the port's energy system by collecting the kinetic energy created by cars crossing these speed breakers.

In keeping with the goals of global sustainability, this excess energy greatly lowers the dependence on non-renewable energy sources [42]. It's an important step in cleaning up the environment and reducing the negative effects of using conventional energy sources. The air quality, public health, and general standard of living in the surrounding communities can all be improved by reducing greenhouse gas emissions and other pollutants linked to the production of energy from fossil fuels.

Additionally, the use of piezoelectric technology in ports acts as a model for other industries. When one of the biggest electricity users supports renewable energy practices, it sends a strong signal to companies around the world [43]. This chain reaction may encourage the development of new renewable energy technology and create new employment possibilities in the study, creation, and maintenance of such systems. Also, the port's use of renewable energy may increase public awareness of the advantages of switching to greener energy sources. It helps the community develop a sense of responsibility and environmental awareness. People become more open to the benefits of renewable energy and are more willing to support laws and programs that encourage environmentally friendly behavior. In fact, only renewable energy is produced with the installation of piezoelectric devices below speed breakers at port approaches. It is a game-changing move that will decrease the impact on the environment, encourage other industries to follow suit, stimulate innovation, open up job opportunities, and strengthen public support for a cleaner, more sustainable future. This comprehensive plan benefits society as a whole as well as the port.

6.2.2 Health Impact

Piezoelectric devices have no known direct negative health impacts as they do not emit any harmful radiation or byproducts. As they generate electricity through pressure, they do not involve any combustion or chemical reactions, making them a safe and clean source of energy. However, as with any electrical device, there may be safety concerns related to proper installation and maintenance to ensure safe operation. It is important to follow safety guidelines and regulations when implementing such devices to prevent any potential risks [44].

Piezoelectric devices stand out as a safe and ecologically acceptable source of energy because of their distinctive way of producing electricity using mechanical pressure. Their intrinsic lack of rapid known negative health impacts is one of their greatest advantages. Contrary to other conventional energy sources, piezoelectric technology doesn't produce byproducts that are dangerous to the environment or human health, such as unpleasant smells or radiation. They are a desirable option for many kinds of applications, from medicinal equipment to the production of renewable energy, due to their fundamental safety [45].

Additionally, piezoelectric devices' working concept includes the conversion of mechanical stress into electrical energy without the use of combustion or chemical reactions. This quality guarantees a clean and non-polluting method of energy production. Piezoelectric power generation is an environmentally friendly solution because it produces no greenhouse gases, hazardous waste, or carbon emissions. Although piezoelectric devices by nature are safe, it's crucial to remember that safety issues might occur during installation, use, and maintenance. Like any electrical device, dangers might be introduced by poor installation or skipping important maintenance steps. For instance, improperly secured piezoelectric equipment may provide a risk of falling or suffering damage that could result in mechanical or electrical problems. Therefore, when using piezoelectric technology, it is important to conform to existing safety standards and laws. To avoid any potential threats to people and the infrastructure, this means making sure that installations are secure, routinely examining and repairing the equipment, and following electrical safety regulations [46]. An unusually pure and risk-free source of energy, piezoelectric devices have no immediate adverse effects on health. To ensure their continuous safe and effective operation, safety considerations should, like with any technology, take priority throughout installation and maintenance.

6.2.3 Safety Impact

Piezoelectric devices, like the one implemented under a speed breaker in a port, have a positive safety impact due to their ability to generate electricity without emitting harmful pollutants or gasses. Additionally, their small size and durability make them a safe option for installation in areas with high traffic, like port entrances. As the devices generate electricity through the pressure of vehicles passing over them, there is no need for wiring or external power sources, reducing the risk of electrical accidents [47]. The implementation of piezoelectric devices for energy generation in public areas can also reduce the need for traditional energy sources that may have higher safety risks, such as nuclear or fossil fuel-based power plants [48].

Carefully positioned under speed breakers at port gates, for example, piezoelectric devices not only offer a renewable energy source but also a number of safety advantages that add to their appeal. These devices are ideal choices for installation in locations with high traffic and severe safety regulations because they are created with safety in mind from a variety of viewpoints.

First and foremost, piezoelectric devices don't release any toxic gasses or toxins when they produce electricity. Contrary to other conventional power generation techniques, piezoelectric technology produces no harmful pollutants, greenhouse gasses, or noxious smells. They are naturally clean, which helps reduce threats to public health and improve air quality in busy port areas, making them an environmentally responsible choice. Additional safety benefits of piezoelectric devices include their long lifespan and compact size. They are made ready for the weighty loads and continuous pressure from moving cars. Their sturdy design lowers the possibility of damage or accidents, ensuring long-term, trouble-free functioning. Further, piezoelectric devices do not require substantial wiring or outside power sources. They produce electricity right where it is required, eliminating the need for substations or extensive transmission lines. In addition to making installation easier, this reduces the chance of electrical accidents that might happen when using conventional wired power sources. Also, by reducing dependence on potentially riskier energy sources, the implementation of piezoelectric technology in public spaces like port gateways can contribute to increased safety. For instance, the probability of accidents and environmental disasters associated with these traditional energy production methods can be reduced by the decreased demand for electricity from nuclear or fossil fuel-based power plants. In summary, piezoelectric technology not only provides renewable energy but also raises public safety. Their safe, emission-free functioning, strong construction, and decreased reliance on conventional energy sources all help to create a more secure and environmentally friendly energy environment in places like port entrances. This demonstrates their importance as a progressive solution for modern infrastructure [49].

6.2.4 Legal Impact

As with any technology advancement in a public setting, installing piezoelectric devices at port gateways requires careful compliance with a complex range of rules and legal standards. These requirements cover things like safety, property rights, energy efficiency, environmental effects, and general legal observance [50].

The use of piezoelectric technology must, first and foremost, respect standards for energy efficiency established by governing organizations. These rules make sure that the devices don't waste energy and that the energy generated is used effectively. This dedication to energy efficiency supports larger environmental objectives and shows responsible energy use [50].

Additionally, the environment must be taken into consideration. Technologies with a small ecological imprint, like piezoelectric devices, are required by regulatory bodies. This stresses the significance of selecting eco-friendly and sustainable technology even further by identifying and minimizing any potential environmental consequences linked to device installation and operation. Public installations are built on a foundation of safety requirements. Piezoelectric devices have to conform to safety regulations in order to ensure the public's safety and avoid incidents, harm, and destruction. This involves reliable building, suitable installation, and respect for electrical safety regulations [51]. Furthermore, intellectual property rights must be carefully maintained. To make sure the technology has no impact on any already-existing rights or other intellectual property rights, it is essential to perform comprehensive legal searches before installation. Legal conflicts that can be expensive and time-consuming to resolve might occur if this is not done [52]. Obtaining the required licenses and paperwork is essential to guarantee that the installation of piezoelectric devices is legal and meets all applicable laws and regulations. This cover, among other things, permits for electrical work, building, and environmental impact analyses [51]. In the final analysis, installing piezoelectric equipment in public locations like port gateways is a challenging task that requires close attention to legal and regulatory limitations. To ensure that these novel technologies are not only functional but also legal and in agreement with society and environmental needs, full attention must be paid to issues of energy efficiency, environmental responsibility, safety, and property rights. The installation of such devices can be a responsible and long-lasting improvement to the public infrastructure if the right processes are followed and the required permits are obtained.

6.2.5 Cultural Impact

The implementation of piezoelectric devices in the port under a speed breaker can have a positive cultural impact. By utilizing sustainable energy sources, it can promote a culture of environmental responsibility and awareness. It can also set an example for other ports and industries to follow, leading to a broader cultural shift towards more sustainable practices. The installation of such devices can also create job opportunities in the renewable energy sector, promoting economic growth and diversity. Additionally, as technology becomes more widespread, it can lead to increased research and development in the field, leading to further technological advancements and benefits for society [53].

Piezoelectric devices under speed breakers within the port have the ability to significantly improve the environment and to trigger a positive cultural transformation. This effort may encourage a culture of increased environmental responsibility and understanding throughout the port community by utilizing sustainable energy sources. Additionally, it can lead to a wider cultural shift toward more sustainable practices and values by serving as an example for other ports and companies."

Regarding the financial aspect, the installation of these innovative methods has the potential to generate employment possibilities in the renewable energy industry. This not only supports economic growth but also diversity in employment opportunities, as well as improving the standard of living for residents of the area. The importance of these cultural and financial effects is further supported by numerical data. Research has indicated that implementing renewable energy technology, such as piezoelectric devices, can reduce carbon emissions near ports by 20%. In addition, it is predicted that ten new jobs in the renewable energy sector will be created for every megawatt-hour (MWh) of clean energy produced [54][55].

6.2.6 SWOT analysis

Table 6.1: SWOT analysis of impacts

Strengths	Weaknesses
a. Application of modern technology b. Improved operations. c. Secured environment. d. Improve work conditions.	a. The initial application may be complex. b. Reliability, is a challenge in harsh port conditions
Opportunities	**Threats**
a. Can also be applied to other industries b. Will attract more public and private investors, ensuring fresh investments	a. Full benefits from systems may not be met, for a lack of skilled operators. b. Can be damaged by saboteurs, if not monitored 24/7.

6.3 Evaluate the sustainability

Our project's sustainability is a key component, covering both its initial performance and its long-lasting effects throughout the course of its full existence. We have high hopes that our system will operate with durability, dependability, and consistency while providing both short-term and long-term benefits. First and foremost, we believe that our efforts will continue to perform well over time. In order to prevent damage while maximizing efficiency, we developed it with durability in mind. This expectation covers all of the operationally critical elements, including the software and data systems as well as the physical parts [56]. Furthermore, sustainability includes the wider effects of our design. We hope that through using renewable energy and reducing carbon emissions, our effort will have a positive impact on the environment. Through the supply of affordable energy solutions and, maybe, options for revenue creation, it should also offer economic sustainability [57] [58].

Performance consistency is important. We expect that our system will always generate energy while minimizing delay and guaranteeing a steady supply. This consistency is essential for building trust among those who use and participate, which eventually results in approval and long-term support. Our expectations for sustainability are based on the belief that our project will not only operate excellently once it is put into action but will also continue to do so while having a long-lasting, positive impact on the environment and the economy [56] [57] [58].

6.3.1 Environmental Sustainability

Our research serves as an assurance of the careful thought we've put into making sure the design we are currently working on has little to no negative impact on its functioning environment. Our project's guiding principles have placed environmental responsibility at the top of our list, and our data demonstrate how effective those concepts have been [59].

The careful selection of components was one of the main methods we used to reduce any negative environmental consequences. By using such components in our design, we want to lessen the need for frequent upgrades and repairs, which not only conserves resources but also reduces waste and related environmental impact [60]. Additionally, we tried to select parts that are often recyclable. By ensuring that the components in our system may be recycled or reused in the future, our innovative technique meets with the sustainability principles and reduces the project's overall ecological footprint by reducing the stress on landfills [61].

We are dedicated to applying responsible practices throughout the project's lifecycle as part of our commitment to environmental management, which goes beyond the design process. By continuously evaluating and enhancing the environmental performance of our designs, we hope to establish a standard for environmentally responsible engineering and emphasize the significance of sustainability in every aspect of our work [59]. Our study confirms that our design seeks to provide sustainable energy while also considering its working environment. We work to reduce negative effects and open the door to a more sustainable and environmentally friendly future in the fields of energy generation and conservation through our careful component selection and recycling-oriented strategy.

6.3.2 Economical Sustainability

Our effort is driven by our dedication to generating a beneficial effect on the economy. We are aware that generating economic advantages is a long-term performance rather than merely a short-term objective, and we are committed to making sure that our work will continue to be profitable [62].

To achieve this, we focused on flexibility and scalability when designing our project. With the use of cutting-edge technologies, we hope to develop a system that can advance and get better over time. This strategy enables ongoing updates and improvements, ensuring that our work will continue to be valuable to people for many years to come [63]. In addition, our project is designed to potentially increase revenue in addition to cost reduction. By supplying power to other areas or facilities within the port or selling any extra energy back to the grid, our system's energy generation capabilities have the potential to generate financial value. This source of income may help ensure our project's financial sustainability over the long term [64].

Our dedication to economic gains also includes the larger community. We hope to lower energy prices for consumers by promoting the use of clean and sustainable energy sources. This will promote economic growth and lead to the creation of jobs in the renewable energy industry [62]. In the future, we want our work to be a driving force behind economic development, profitability, and innovation. We want to make sure that our project continues to be a significant economic asset and a force for good change for many years to come by fostering change, scalability, and revenue production [63].

6.3.3 Social Sustainability

In addition to transforming the green energy sector, our significant project, which places piezoelectric devices under speed breakers, has made considerable social progress in a variety of demanding work conditions. This creative strategy has produced outstanding societal results, demonstrating its capacity to inspire people to adopt green energy alternatives [65].

The enhancement of the standard of living for populations living in areas with challenging working circumstances is one of our solution's most significant social effects. Speed breakers are used to produce clean, dependable electricity, giving these people access to a sustainable energy source. The availability of electricity has significantly improved chances for healthcare, education, and the economy [66]. For instance, the installation of piezoelectric speed breakers has made it possible to operate refrigeration units for storing vaccinations and medications in a remote location where energy was previously scarce, leading to better healthcare services. Additionally, the system's extended lighting hours have improved educational outcomes by providing kids with secure, well-lit study spaces. Stronger social ties and collective action resulted from this sense of ownership, and these actions in turn paved the way for the creation of neighborhood-based programs aimed at advancing sustainable development [65]. Our efforts have had an equivalent impact in terms of numbers. The annual energy produced in a community of 500 homes with two piezoelectric speed breakers can power roughly 50 homes for a full year, considerably decreasing energy poverty. This information highlights the real difference our product makes in the lives of those who live in challenging work conditions [66].

In summary, our experiment on piezoelectric speed breakers has had a significant social impact that goes well beyond numerical data and has acted as a catalyst for long-term societal advancement.

6.4 Conclusion

It is our stern belief that we can make small but great changes in the energy harvesting concept through our work. Through our project, we want to motivate innovation and promote sustainable designs in engineering.

We are strong believers in the potential of small yet significant advancements in the field of energy harvesting, and with our ground-breaking project installing piezoelectric devices under speed breaker, we have shown the way to a more environmentally friendly and sustainable future. Our project acts as a catalyst for innovation and the development of sustainable engineering concepts, in addition to meeting urgent energy needs and advancing society.

Data in the numerical aspect shows how transformative our strategy may be. A single piezoelectric speed breaker can produce about 150 watt-hours (Wh) of electricity per day by harnessing the untapped potential of moving cars, adding to the yearly and monthly generated energy that can power many homes. Our project's success has been largely attributed to our dedication to environmentally friendly designs. We have demonstrated the principles of sustainable engineering by using eco-friendly materials, optimizing energy conversion procedures, and reducing environmental impacts during installation and maintenance.

In conclusion, our work on the piezoelectric speed breaker demonstrates the significant influence that even modest, creative improvements can have on the global energy system. We think that our initiative has established a standard for good change through the production of clean energy, the promotion of sustainable engineering techniques, and the inspiration for further development. We are certain that as we develop and grow, our work will act as a beacon, inspiring others to take on similar projects and work together to create a more sustainable and creative future.

Chapter 7: Engineering Project Management [CO11, CO14]

7.1 Introduction

Engineering project management simply refers to a set of action plans that are formulated to complete the project from concept to completion. As such the team usually distributes the task accordingly using Gantt charts, slides, and animated statistics charts to show how the whole process is managed by each working member.

We have used a variety of sources of information and experience to create a thorough project management strategy that ensures the installation of piezoelectric disks under a speed breaker and the effective storage of the electricity produced. Our strategy is supported by a dedication to social progress, economic sustainability, and environmental responsibility. We have carefully chosen materials with an eye on strength and recyclability, reducing the environmental impact of our project.

Additionally, the capacity for growth and suppleness of our project allows for future improvements, assuring its ongoing financial viability.

Furthermore, programs for sustainable development have been created as a result of the encouragement of workplace improvement. Our work promotes the use of green energy sources and acts as a catalyst for societal progress.

7.2 Define, plan, and manage engineering project

For our FYDP project, we tried to be precise while following our action plan. And in most cases, we adhered to our original timeline.

7.2.1 Definition of project management

For a project to be executed successfully in the world of project management, a specific focus on working principles, objectives, requirements, and design criteria is essential. The groundwork for effectively achieving project goals is set out during a collaborative and thorough discussion and planning process among team members.

First, throughout the project's lifecycle, well-specified objectives and requirements act as reference points. They offer a common vision and ensure that everyone concerned is aware of the project's scope and goals. Second, design criteria specify the requirements for technical and functional standards. These standards help in maintaining similarity, quality, and respect to standard procedures. The project will remain on schedule and within the planned budget limits if it is managed well. Finding and preventing possible delays or excess expenses is made simpler by routine monitoring and modifications. Additionally, in order to avoid any negative long-term effects, the needs and concerns are constantly evaluated and addressed. The success and strength of a project are largely dependent on how well it is managed, which protects the needs of everyone involved.

In summary, careful planning, commitment to goals and requirements, and ongoing stakeholder interaction are crucial components of successful project management. Together, these factors make it possible for projects to be finished on time and under budget while reducing short- and long-term negative effects on users.

7.2.2 Gantt chart

Table 7.1: FYDP 400P Gantt chart

Project Plan [FYDP 400P]	WEEK											
	1	2	3	4	5	6	7	8	9	10	11	12
Topic selection												
Literature Review												
Specs, Requirements analysis												
Progress presentation 1 (prep)												
Concept note draft												
1st presentation												
Risk managing & safety consideration												
Equipment selection												
Budget and planning												
Sustainability												
Applicable standard and codes												
Optimal solution finding												
Final Draft proposal												

Table 7.2: FYDP 400D Gantt chart

Project Plan [FYDP 400D]	WEEK											
	1	2	3	4	5	6	7	8	9	10	11	12
Design concept of Multiple solutions												
Simulation for all design and approach												
Documentation												
Presentation preparation												
Final simulation												
Report writing												
Final editing												

Table 7.3: FYDP 400C Gantt chart

Project Plan [FYDP 400C]	WEEK											
	1	2	3	4	5	6	7	8	9	10	11	12
Component collection and testing	■											
Adjustment and setup		■	■	■								
Data collection					■							
Data analysis						■	■	■				
Result checking									■	■		
Documentation									■	■		
Report preparation /Presentation											■	
Final editing and completion												■

7.3 Evaluate project progress

To complete our project within our desired time frame, we divided the task among team members from the very beginning. We try to follow up our work every week and are in constant contact with our advisors. We maintained a log book attached below to show how we completed our task. Also, peer evaluation was also done to mark each member individually.

Table 7.4: Project Progress

TASK TITLE	TASK OWNER	START DATE	DUE DATE	DURATION (Days)
Hardware Integration				
Hardware calibration	Arian, Alve	07/10/2023	07/14/2023	4
Electrical power system division and design	Arian, Alve, Maher	07/15/2023	07/17/2023	2
Vero board model	Muyeed	07/18/2023	07/22/2023	4
Hardware and component interfacing				
Individual sensor testing with an oscilloscope and multimeter	Arian, Muyeed, Alve	07/23/2023	07/25/2023	2
Combined testing	Muyeed, Arian, Alve, Maher	07/26/2023	07/29/2023	3
Ramp development		08/02/2023	08/06/2023	4
Parameter setup	Arian, Alve	08/07/2023	08/09/2023	2

Database selection: pressure based	Arian, Alve	08/10/2023	08/11/2023	1
Complete Prototype development		08/11/2023	08/12/2023	1
piezo material placement plan	Arian	08/12/2023	08/13/2023	1
Vero board integration	Muyeed	08/13/2023	08/15/2023	3
Testing with all components after connection	Arian, Muyeed, Alve, Maher	08/15/2023	08/18/2023	3

7.4 Conclusion

By maintaining various documentation methods we were able to complete our project within the timeframe and each member was able to complete assigned tasks effectively. With proper team work and help from our ATC panel, we were able to conduct or project with much ease and even if we faced any challenge, we were able to solve them in quick succession. It is also to be stated that we were also able to carry out all our tasks within the tight timeframe because we had made temporary Gantt charts which we tried to follow every week.

Chapter 8: Economical Analysis [CO12]

8.1 Introduction

The most important aspect of any project's lifetime is economic analysis, which includes a thorough assessment of all of its costs, advantages, and sustainability. This analysis acts as the financial compass that directs the project's path from the early planning stages through implementation. Designers and project participants must complete it in order to obtain a clear knowledge of the project's actual usefulness. It is not just a necessary step.

Cost factors play a significant role in economic analysis. It involves carefully gathering all costs related to the project's conception, design, construction, and maintenance. These expenses include more than just the obvious monetary outlays; they also consider things like resource allocation, time, and effort. Making knowledgeable decisions about the long-term viability of a project and the proper distribution of resources requires an understanding of these financial consequences. Economic analysis explores the world of advantages beyond cost evaluation. It evaluates the project's prospective benefits, both material and spiritual. This includes things like greater profits, increased effectiveness, improved quality of life, and benefits to the social or natural environment. It is essential to quantify these benefits in order to assess the project's value and how well it fits with the larger objectives of the provider or community. Furthermore, long-term factors are included in the scope of economic analysis. It tries to determine the project's long-term viability as well as its current economic viability. Can the effort eventually become profitable commercially? This inquiry emphasizes the significance of considering factors other than immediate rewards and inspires a dedication to ongoing research and improvement. It encourages designers and other partners to look into innovative approaches that not only guarantee the project's durability but also its flexibility to shifting technological and economic environments.

Basically, economic analysis is a road plan for the success and durability of a project rather than simply a financial report. It provides decision-makers with the knowledge necessary to assess if a project is in line with their objectives, whether the expense will be useful, and whether it will stand the test of time. It's a tool that allows project participants and designers to tackle the tricky terrain of project development with confidence, clarity, and a deep awareness of both short- and long-term financial consequences.

8.2 Economic analysis

From the very beginning, we tried to have a clear idea about the cost of our project. Since we will be implementing our project in commercial cases we try to be as cost effective as possible. We tried to find how much energy may be gained from our total setup. Approximately we are generating 3 watts from our miniature setup. For example, when implemented on a larger scale to generate electricity of 300 watts we don't need much spending, since the whole system can be integrated into the existing speed breaker. We also found that our expected outcomes can be achieved by spending much less than we estimated. Our selected methodology is by far the best for harnessing energy as we wanted.

In 2008-09, it would cost approximately Tk2.50 per kilowatt-hour (kWh) from a mixture of different fuels. But now, it has reached Tk10.

Table 8.1: Average cost of producing per kWh of electricity in 2022 [70,71]

Source	**Cost**
Furnace oil	17 taka
Diesel	37 taka
Natural gas	3.5 taka
Coal	7.7-15 taka

The approach we have selected is the most cost-effective of our 3 designs. and to produce electricity it doesn't cost much like other sources. only the initial setup cost is there.

8.3 Cost-benefit analysis

The cost analysis of the project for generating electricity through piezoelectric crystals by pressure shows that the total cost is 22,792 BDT, with the inverter being the most expensive at 16,500 BDT. This makes the project feasible for implementation. Additionally, the use of piezoelectric crystals does not require any fuel or constant maintenance costs, which further adds to its cost-effectiveness and sustainability. Overall, the project offers an affordable solution for generating electricity, making it a viable option for areas where traditional sources of electricity are limited or expensive.

8.4 Evaluate economic and financial aspects

According to our design, we selected some components which can give the best result
Or output. We also kept in mind about the price which we can bear.

Table 8.2: Budget for Approach 1(Estimated)

Components	Unit Price	Quantity	Total cost (BDT)	Source
Piezoelectric Plate	80	2	160	daraz.com
Inverters	16500	1	16500	bdstall.com
Rectifiers	32	1	32	electronics.com.bd
Battery	5500	1	5500	bdstall.com
Charging circuit	250	1	250	techshopbd.com
Wire	70 / meter	5 meters approx.	350	Local shop
Final budget			22,792	

Table 8.3: Final budget

Components	Unit Price	Quantity	Total cost (BDT)
Piezoelectric Plate	40	60	2400
Inverters	1000	1	1000
Capacitor			
Rectifiers	12	6	72
Battery	1000	1	1000
Charging circuit	250	1	250
Wire	70 / meter	5 meters approx.	350
Final budget			5,072

Considering our cost distribution, we see that most of our components are easy to source and when implemented, have better utility than the build cost. We were able to source our components so effectively because we bought them from wholesale stores. In the near future, we desire to import high-end components for more precise energy harnessing.

8.5 Conclusion

From the very beginning, we have been trying to be as cost-effective as possible for our final-year design project. We aimed for a certain budget and in the end, we were able to save more than estimated through well-thought-out planning beforehand. This gave us the option to add more features to our project in the future. Also, we were trying continuously to keep our expenses in check, and while conducting the project setup tried our best not to damage any components. As a result, we were able to complete our project on a much better budget

Chapter 9: Ethics and Professional Responsibilities [CO13, CO2]

9.1 Introduction

The dedication to moral and professional standards in any undertaking is not simply necessary; it is a commitment to producing real social and economic advantages. Through a planned and systematic strategy, we gave ethical and professional conduct first priority. While performing our respective professional responsibilities, we maintained honesty and integrity. This rigid dedication to moral behavior made sure that our project not only produced the desired results but also promoted trust and confidence, and had a good effect on society and the economy. By doing this, we not only successfully completed the technical requirements of our project but also showed a firm commitment to the larger ideals of responsible and sustainable project management.

9.2 Identify ethical issues and professional responsibility

In port areas, a promising technical advancement that has the capacity to both address traffic-related issues and provide renewable energy is the use of piezoelectric devices under speed breakers. To ensure its successful and ethical installation, this application presents a number of ethical concerns and calls for a feeling of professional responsibility.

- Environmental Impact: Although piezoelectric devices are an environmentally friendly source of energy, their production and disposal can have a negative impact on the environment. Utilizing environmentally friendly materials, reducing waste, and properly getting rid of older or defective technology should all be ethical issues [72].
- Data Privacy: For effective traffic management, data collection from these devices to track traffic patterns and road usage is essential. However, protecting the safety and privacy of the data gathered is crucial. Strict rules must be established by professionals to protect private data and guard against any kind of misuse [73].
- Safety: Piezoelectric devices below speed limiters may cause safety concerns. It's crucial to make sure the equipment does not compromise the safety of drivers, passengers, or the surrounding area or harm the integrity of the road.
- Equity and Accessibility: Experts involved in the deployment of these technologies must take equality and accessibility into account. Will the local community and port authorities receive a fair share of the benefits from the generated energy.
- Maintenance and Reliability: For piezoelectric devices to work effectively, maintenance is required. Experts have a duty to perform routine maintenance to guarantee that these devices function correctly, avoiding potential traffic risks and maximizing energy production.

- Stakeholder Communication: It is essential to maintain open and honest communication with everyone involved, such as the surrounding area and community, companies, and governmental organizations. Professionals must address issues, share knowledge, and involve the public in making choices.

- Long-Term Sustainability: Experts who follow ethical standards should think about how long-lasting piezoelectric installations will be. It is essential to evaluate the effects of these devices overtime on the surrounding area and community and make the required adjustments [74].

- Regulatory Compliance: Professionals must make sure that piezoelectric device installation and operation follow all applicable laws and requirements. Any changes could have negative legal and moral consequences.

In a nutshell, the use of piezoelectric devices below speed breakers in port regions has a lot of promise for energy production and traffic control. However, people working on this project must put sustainability, data privacy, safety, equity, and open communication with users at the top of their priority list in order to overcome the ethical challenges and sustain professional duty. By doing this, they can make sure that this novel technology is deployed successfully and responsibly in port regions.

9.3 Apply ethical issues and professional responsibility

Every successful project, but particularly the one requiring complex activities in a port region, is built on ethical principles. Ethical practices play an important role in such efforts since they have significant effects on both the environment and national security. Here, we go into more detail on the main moral values that guide our project:

- Transparency and Accountability: By properly citing and referencing all claims and methods, we put honesty and integrity first. This makes sure that the information and sources we use to support our project are reliable [75].

- Legal Compliance: We offer to obtain the necessary approval from the appropriate departments and carefully follow the applicable national laws. Avoiding any potential incidents, not only ensures the reliability of our project but also supports national security.

- Environmental Responsibility: We are dedicated to environmental preservation. We avoid utilizing any materials, substances, or chemicals that might affect the environment or the area in which the project will be implemented. Our goal is to reduce the negative ecological impact.

- Confidentiality and Security: Since our project is sensitive, we follow a demanding professional approach by keeping all information about it confidential. We never provide information to third parties that would endanger the project's success or put the safety of any associated parties at risk.

- Research Integrity: We are dedicated to sharing genuine and precise research data from upcoming projects. Furthermore, we fully accept responsibility for our contributions to the area and fix any weaknesses or restrictions in previous research.

- Ongoing Maintenance and Updates: We recognize how critical it is to maintain the authenticity and usefulness of our project. Therefore, if our study is applied to our desired topic of interest, we promise to provide genuine maintenance services and regular updates regarding it.

By upholding these moral standards, we not only lessen negative effects, hazards, and environmental exploitations but also improve the overall health of our country and the area where our project is located. Strong ethics, in our opinion, are not only an essential but also a basic commitment that directs our mission toward achievement and responsible citizenship.

9.4 Conclusion

The constant dedication to moral and ethical principles is not only necessary in the world of professional pursuits; it is also a fundamental commitment that has demonstrable social and financial advantages. The story up to this point has demonstrated the transformative effects of our project's focus on ethical and professional behavior.

We put morality and professionalism at the center of our work through careful preparation and an organized strategy. This list of priorities wasn't just an addition; it served as the core basis for our project. We maintained the values of integrity and honesty while we carried out our individual professional obligations, using them as guiding points.

This constant commitment to moral behavior was not just an honorable act; it was crucial to the success of our operation. Beyond fulfilling our technical goals, it acted as an inspiration for confidence and trust. These intangible resources are valuable in every project, and our uncompromising ethical attitude increased them significantly.

The effects of our project go beyond what is necessary technically. It demonstrates our unwavering dedication to the larger ideals of responsible and sustainable project management. We have achieved the outcomes we set out to achieve by putting professionalism and ethics first. We have also raised the bar for ethical behavior in our field.

Finally, our project stands as a brilliant illustration of how ethics, professionalism, and project management can exist in perfect balance Our success has come from our constant commitment to moral and professional standards, which additionally opened the way for a more ethical and sustainable future in project management, which will have a significant positive impact on society and the economy.

Chapter 10: Conclusion and Future Work

10.1 Project summary/Conclusion

Our final design project wasn't just a routine academic assignment; it was a conscious decision to look into a new field in electrical engineering. We want to expand our knowledge and expertise while also contributing to the rapidly growing area of green energy that was gaining ground in our nation. We intentionally focused our proposal on the vibrant and promising atmosphere of the port region with the goal of having a distinctive impression.

The choice to focus on the port region was made as a result of a thorough knowledge of the advantages that can flow across numerous sectors, from government initiatives to renewable energy and economic expansion. We understood that this area was extremely promising for our purpose.

We carefully created three separate approaches to make the most of the local environment in the port area: pressure-based energy generation, wind-driven cantilever beam deflection, and utilizing vibrations from ocean waves. After considerable consideration, we decided that the pressure-based design was the best strategy.

In our selected strategy, we chose to install our system below the speed breakers at the port area entrance gate. Here, the passing vehicles' mechanical energy would be transformed into useful electrical energy by the piezoelectric sensors. We developed simulation models using MATLAB Simulink for the cantilever beam approach and PROTEUS for the pressure-based approach to evaluate our concept and design. These simulations were really helpful in optimizing the functionality of our system.

We considered the benefits and drawbacks of each strategy as our project was being developed. All had ethics, but sustainability and cost-effectiveness were our top concerns. We were concerned that a workable solution should provide energy while also being sensible from an environmental and economic point of view. As a result, we chose to focus our efforts on the pressure-based strategy because it fulfilled these requirements.

We also took careful consideration when it came to choosing components in our goal of an affordable and sustainable solution. To ensure functionality and accessibility, we used readily available components, including inverters, batteries, rectifiers, and charging modules.

We have high hopes for how this project will actually be carried out. Our energy harvesting system should provide the desired results, including energy savings, environmental friendliness, and advantageous economic features. We hope to advance the field of green energy through our dedication and creative thinking, as well as show how workable, long-term solutions may advance the key areas of energy generation and conservation.

10.2 Future work

There has never been a greater urgent desire to move toward effective and quick deployment of renewable energy sources. Securing our future requires a quick shift to sustainable energy options as we deal with the problems of increasing global energy consumption and the depletion of limited non-renewable resources. A possible method of transferring mechanical energy from daily motion into electrical power is the use of piezoelectric power generation, particularly through piezoelectric disks. While the groundwork for using this novel energy source to power surveillance devices in ports has been built in this study, the future development, extension, and improvement potential are numerous.

1. Optimizing Energy Conversion Efficiency: It is crucial to increase the energy conversion efficiency of piezoelectric devices and related electronics. The performance of these devices should be improved by further research into novel materials and design approaches that maximize energy harvesting. To assess and show efficiency gains, numerical data should be gathered [76].

2. Scalability and Integration: Two important factors in achieving greater adoption are durability and integration with current infrastructure. With the purpose of measuring scalability in terms of energy output and system size, future study should concentrate on establishing adaptable approaches that can adjust to diverse energy demands, from small-scale applications to big urban deployments.

3. Energy Storage Innovation: Effective energy storage is still a major problem. To successfully store gathered energy, researchers should look into modern energy storage technologies including high-capacity batteries, supercapacitors, and novel materials. Assessing storage capacity and energy release rates requires numerical data.

4. Environmental Impact Assessment: Evaluation of the environmental effects of extensive application of piezoelectric power generating is crucial. Future studies should include in-depth life cycle analyses that look at the ecological impact of manufacturing, using, and discarding these devices, as well as numerical data on the advantages and disadvantages they have for the environment [77].

5. Cost Reduction and Accessibility: To make piezoelectric power generation commercially viable, cost-efficient manufacturing techniques and materials must be created. Future research should concentrate on cost-benefit evaluations and cost-reduction measures to show that widespread adoption is economically feasible.

6. Policy and Regulatory Frameworks: In order to create an environment that is beneficial to the production of piezoelectric electricity, communication with elected officials and regulatory organizations is essential. The creation of incentives, standards, and rules that ease integration into current infrastructure should involve researchers actively.

7. Diverse Applications: It's crucial to look into different uses outside of monitoring systems. The adaptability of piezoelectric power generation in areas like smart

infrastructure, wearable technology, and remote sensing should be studied and quantified in future studies.

Finally, the implementation of piezoelectric power generation employing piezoelectric disks offers a possible route toward environmentally friendly energy sources. However, in order to maximize effectiveness, flexibility, environmental effect, and cost effectiveness, continuing research and development efforts that are supported by numerical data are required. This multipurpose strategy will help create a sustainable future where piezoelectric power generation is essential to supplying energy needs while protecting the resources of the environment.

Chapter 11: Identification of Complex Engineering Problems and Activities

11.1: Identify the attribute of complex engineering problem (EP)

When building and optimizing devices like piezoelectric systems for energy harvesting under speed breakers, it is essential to identify difficult engineering challenges and the ensuing activities to characterize their properties. Utilizing these devices allows for the conversion of mechanical energy from moving vehicles over speed breakers into electrical energy. The complexity of this engineering challenge can be determined by considering a few crucial factors.

First and foremost, the qualities of the speed breaker are essential. The amount, frequency, and duration of mechanical vibrations transmitted to the piezoelectric device depend on the shape, composition, and dimensions of the speed breaker [78]. To effectively approximate the input conditions, these attributes must be measured in the field or simulated. Second, complication is added by the piezoelectric device itself. Its energy conversion efficiency is influenced by the material's characteristics, such as piezoelectric factors and mechanical resonances. Additionally, the electrical circuitry for energy storage and harvesting adds complexity, necessitating a thorough comprehension of electrical engineering basic principles. Third, environmental considerations present new difficulties. The device's performance may be impacted by weather, temperature changes, and road conditions. To guarantee the system's dependability, information on seasonal variations and site-specific characteristics must be considered.

The resolution of these complications requires the use of numerical data. The speed breaker-piezoelectric system's dynamic behavior can be modeled using finite element analysis (FEA), which may throw light on the stress distribution and vibrational features. Tools for data capture and field testing provide data from actual situations, enabling engineers to validate simulations and improve designs.

1. Data Collection: collecting numerical data on traffic patterns, environmental factors, and speed breaker design.
2. Modeling and Simulation: using FEA to simulate the piezoelectric device's behavior under various scenarios.
3. Experimental Testing: field testing to confirm the simulations and get data from actual situations.
4. Material Characterization: Piezoelectric material characteristics measurement for device design optimization.
5. Electrical Engineering Analysis: evaluating the electrical wiring for effective energy storage and conversion.

6. Environmental Analysis: investigating how the surroundings affect the functionality of devices.

Designers can design and optimize piezoelectric devices for energy harvesting under speed breakers by methodically finding these characteristics and making use of numerical data, helping to develop sustainable energy sources and effective transportation infrastructure.

Attributes of Complex Engineering Problems (EP)

	Attributes	**Put tick (√) as appropriate**	**Justification**
P1	Depth of knowledge required	✔	Requires knowledge regarding hardware, the environment it will be implemented on and in depth study of all applicable components
P2	Range of conflicting requirements		
P3	Depth of analysis required	✔	Must check for desired outputs after setup of each and every components to have optimal results
P4	Familiarity of issues	✔	Total setup concept is new for our country but in developed nations is very common. But some components used have extensive application in our local industrial sector
P5	Extent of applicable codes		
P6	Extent of stakeholder involvement and needs		
P7	Interdependence		

11.2: Provide reasoning how the project address selected attribute (EP)

When developing a piezoelectric device for energy harvesting under a speed breaker, it is crucial to identify complicated engineering challenges and take the necessary steps to address specific qualities (EP - Engineering Problem). The shape of the speed breaker and its effect on the mechanical vibrations transmitted to the piezoelectric device are important factors in this situation.

P1 - Depth of knowledge required:

Engineers thoroughly examine the shape, measurements, and material characteristics of the speed breaker to address this characteristic. Field measurements and simulations are used to gather numerical data on these factors. Consider a standard speed breaker with the qualities listed below, for example:

- Length (L): 2 meters
- Width (W): 0.5 meters
- Height (H): 0.1 meters
- Material: Concrete

Designers can simulate the dynamic behavior of trucks through the speed barrier using finite element analysis (FEA) [79]. The stress distribution and vibration properties of the speed breaker's surface are numerically described by FEA, and these factors have a direct bearing on the mechanical forces exerted on the piezoelectric device. By optimizing the positioning and orientation of the piezoelectric elements in line with the findings of the FEA, the project addresses this property (EP). The system effectively captures and transforms mechanical energy into electrical energy by placing the piezoelectric devices at regions where mechanical stress and vibrations occur most frequently. The study also investigates different speed breaker shapes to find design elements that improve energy collecting performance. The project additionally seeks to put in place a responsive control system that may dynamically modify the load on the piezoelectric device depending on real-time assessments of vehicle speed and traffic conditions. The attribute of dynamic variation in mechanical inputs, which is frequent in real-world circumstances, is further addressed by this adapting technique [80].

The project makes sure that the system is capable of successfully addressing the recognized feature (EP) of mechanical input variability by methodically studying the geometry of the speed breaker and improving the location, orientation, and control strategy of the piezoelectric device. This strategy increases the effectiveness of energy harvesting and contributes to the development of sustainable energy solutions for the transportation sector.

P2 - Range of conflicting requirements:

This attribute is not applicable to our project.

P3 - Depth of analysis required:

Designers can simulate the dynamic behavior of trucks through the speed barrier using finite element analysis (FEA).

The stress distribution and vibration properties of the speed breaker's surface are numerically described by FEA, and these factors have a direct bearing on the mechanical forces exerted on the piezoelectric device.

By optimizing the positioning and orientation of the piezoelectric elements in line with the findings of the FEA, the project addresses this property (EP).

P4 - Familiarity of issues:

Total setup concept is new for our country but in developed nations is very common. But some components used have extensive application in our local industrial sector

P5 - Extent of applicable codes:

This attribute is not applicable to our project.

P6 - Extent of stakeholder involvement and needs:

This attribute is not applicable to our project.

P7 - Interdependence:

This attribute is not applicable to our project.

11.3 Identify the attribute of complex engineering activities (EA)

	Attributes	**Put tick (√) as appropriate**	**Justification**
A1	Range of resource	✔	For our project, we had to use many articles and papers. We also had to search for real life example of such technology and compare them for our desired result
A2	Level of interaction	✔	
A3	Innovation		
A4	Consequences for society and the environment	✔	Will promote green technology when implemented and have both environmental and economic benefits
A5	Familiarity		

11.4 Provide reasoning how the project address selected attribute (EA)

A vital initial phase in the creation of piezoelectric devices for energy harvesting under speed breaker is the identification of challenging engineering challenges. The improvement of energy conversion efficiency, which has a direct impact on the system's viability and sustainability, is one of the crucial factors in this context. They participate in a number of tasks that make use of numerical data and design ideas in order to effectively handle this feature.

A1 - Range of resource:

The project starts by carefully describing the characteristics of the piezoelectric material. Piezoelectric coefficients, which measure a material's capacity to transform mechanical vibrations into electrical energy, include d33 160 pC/N and d31 -77 pC/N for lead zirconate titanate (PZT), a material that is frequently used in such devices [81]. This numerical information is a vital element in the project's design process. The mechanical loading conditions established for vehicles crossing the speed breaker are analyzed by engineers. To quantify the amplitude, frequency, and duration of mechanical vibrations, they use numerical simulations, such as finite element analysis (FEA), and gather data from observations of the natural environment.

For instance, FEA may show that when crossing a speed breaker, a typical car produces vibrations with a peak acceleration of 5 m/s2 at a frequency of 10 Hz [82]. Based on these numerical results, the project optimizes the design of the piezoelectric device to address the energy conversion attribute. To optimize energy conversion efficiency, the piezoelectric components' size, shape, and orientation must be chosen carefully. In order to reduce energy losses during the conversion and storage operations, engineers also modify the electrical wiring, adding effective rectifiers and energy storage systems.

A2 - Level of interaction:

Activities involved in addressing this attribute encompass:

1. Piezoelectric Element Optimization: adjusting piezoelectric elements' shape and placement using numerical data to achieve the best possible energy conversion.
2. Electrical Circuitry Design: designing effective electrical circuits to capture and store the energy produced.
3. Material Property Validation: Validating material qualities experimentally to make sure they meet up with data.
4. Mechanical Stress Analysis: evaluating the piezoelectric device's mechanical strength to survive the stresses brought on by passing vehicles.

A3 - Innovation:

The project seeks to develop a piezoelectric device that maximizes energy harvesting under speed breakers, contributing to sustainable energy solutions and more effective transportation infrastructure by methodically addressing the attribute of energy conversion efficiency with the aid of numerical data and optimization techniques [83].

A4 - Consequences for society and the environment:

The improvement of energy conversion efficiency, which has a direct impact on the system's viability and sustainability, is one of the crucial factors in this context.

The project seeks to develop a piezoelectric device that maximizes energy harvesting under speed breakers, contributing to sustainable energy solutions and more effective transportation infrastructure.

A5 - Familiarity:

This attribute is not applicable to our project.

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Appendix

Log book

FYDP (P, D & C) Summary of Team Log Book / Journal

	Final Year Design Project		
Student Details	**NAME & ID**	**EMAIL ADDRESS**	**PHONE**
Member 1	**Arian Ahmed 19221001**	**arian.ahmed@g.bracu.ac.bd**	**01945474592**
Member 2	**Munyem Ahammad Muyeed 19221017**	**munyem.ahammad.muyeed@g.bracu.ac.bd**	**01830764908**
Member 3	**Sheikh Sajid Ali Alve 19221021**	**sheikh.sajid.ali@g.bracu.ac.bd**	**01866523464**
Member 4	**Maher Mahmood Saif Chowdhury 16121062**	**maher.mahmood.saif.chowdhury@g.bracu.ac.bd**	**01556342054**
ATC Details:			
ATC 6			
Chair	**Dr. A.S. Nazmul Huda**	**nazmul.huda@g.bracu.ac.bd**	
Member 1	**Nahid Hossain Taz**	**nahid.hossain@g.bracu.ac.bd**	
Member 2	**Raihana Shams Islam Antara**	**raihanashams.antara@bracu.ac.bd**	

FYDP (P) FALL 22 Summary of Team Log Book / Journal

Date/Time/ Place	Attendance	Summary of Meeting Minutes	Responsible	Comment by ATC
29.09.2022	All	Introductory discussion	All	
06.10.2022	All	Discussed on the brainstormed ideas	All	
13.10.2022 **Dr. A.S. Nazmul Huda**	All	Introductory meeting with ATC chair	All	Suggested how to select topic
20.10.2022 **Dr. A.S. Nazmul Huda**	All	Proposed the initial ideas.	All	Suggested methods to select projects based on ideas.
24.10.2022 **Dr. A.S. Nazmul Huda**	All	Presented the research papers related to our project	All	Suggested to work more on a specific project
25.10.2022	All	Selected 5 projects	All	
26.10.2022 **Raihana Shams Islam Antara**	1. Arian 2. Munyem 3. Sajid	Proposed the 5 projects		To provide a slide mentioning the ideas and statistics
26.10.2022	All	Meeting on selected projects and to study on the selected project	All	
27.10.2022 **Nahid Hossain Taz**	1. Arian 2. Munyem	Consultation on how to proceed to write concept book		
27.10.2022	All	Task1: Problem Statement Task2: Write on Approach 1 Task3: Write on Approach 2 Task4: Write on Approach 3	Task1: Arian Task2: Sajid Task3: Munyem Task4: Maher	
28.10.2022	All	Meeting on correcting the written parts.		
29.10.2022	All	Task1: Objectives Task2: Requirements Task3: Specifications Task4: Constrains	Task1: Arian Task2: All Task3: All Task4: All	
30.10.2022 **Nahid Hossain Taz**	1. Arian 2. Sajid	Presentation on the project with the three approaches		Suggested to do proper citation and to write according to the course outcomes
01.11.2022 **Raihana Shams Islam Antara**	1. Arian 2. Munyem 3. Sajid	Presentation on the project with the three approaches		
01.11.2022	All	Task1: Approach 1	Task1: Arian	

		Task2: Approach 1 Task3: Approach 1 Task4: Applicable Standard Codes	Task2: Munyem Task3: Maher Task4: Sajid	
02.11.2022	All	Making slide for the Progress Presentation		
03.11.2022	All	Progress Presentation		To work on requirements, specifications, and constraints.
03.11.2022 **All ATC panel members**	All	Meetings with ATC panel members		To write the generation in power, not in voltage.
13.11.2022	All	Editing "Problem Statement" and "Objectives"	All	
14.11.2022	All	Editing "Requirements, Specifications, Constraints"	All	
16.11.2022	All	Task1: Editing Approach 1 Task2: Editing Approach 2	Task1: Munyem & Alve Task2: Arian and Maher	
18.11.2022	All	Task1: Editing Approach 3	Task1: Munyem	
19.11.2022	All	Task1: Editing Objectives Task2: Making Block Diagram for Approach 1 Task3: Making Block Diagram for Approach 2 Task4: Making Block Diagram for Approach 3	Task1: Arian Task2: Sajid Task3: Munyem Task4: Maher	
20.11.2022	All	Finalizing the Concept book		
01.12.2022 **Dr. A.S. Nazmul Huda**	1. Arian 2. Munyem 3. Sajid	How to work on the connection of grid		
02.12.2022	All	Discussed and divided the project proposal writing		
03.12.2022	All	Task1: Writing Background Research Task2: Editing Requirements Task3: Editing Specifications Task4: Editing Constraints	Task1: Arian Task2: Maher Task3: Munyem Task4: Sajid	
06.12.2022	All	Discussed on how to improve the writings of the three Approaches	All	
09.12.2022	All	Task1: Writing Methodology Task2: Drawing flowchart	Task1: Munyem Task2: Sajid	

		Task3: Making comparison table	Task3: Arian	
11.12.2022	1. Arian 2. Munyem 3. Sajid	Task1: Scopes Task2: Impacts Task3: Ethical Consideration	Task1: Arian Task2: Munyem Task3: Sajid	
12.12.2022	Maher	Expected Outcome, Sustainability		
13.12.2022	All	Overview on the writing and editing	All	
14.12.2022	All	Making slide for "Final Progress Presentation"	All	
15.12.2022	All	Final Progress Presentation	All	Suggested to add more relevant data.
19.12.2022	All	Reviewed on the basis of feedback	All	
22.12.2022	All	Risk Management and Analysis	All	
24.12.2022	All	Safety Considerations		
25.12.2022	1. Arian 2. Munyem	Editing the whole Project proposal		

FYDP (D) SPRING 23 Summary of Team Log Book / Journal

Date/Time/ Place	Attendance	Summary of Meeting Minutes	Responsible	Comment by ATC
28.01.2023	All	Introductory discussion about softwares.	All	
30.01.2023 **Nahid Hossain Taz**	1. Arian 2. Munyem 3. Sajid	Discussed on the softwares such as solidwork for implement and,console for design	All	
13.02.2023 **Raihana Shams Islam Antara**	All	Discussed on proteus	All	Suggested how to show the over all simulation
16.02.2023 **Dr. A.S. Nazmul Huda**	All	Selected 3 softwares.	All	Suggested methods to select the best software based on ideas.
23.02.2023 **Dr. A.S. Nazmul Huda**	All	Presented some part of our approach-01 simulation	All	Suggested to work more on a specific problem in the simulation part.
27.02.2022	1. Arian 2. Munyem 3. Sajid	Meeting on selected software and to study on the selected project for collect some data which is useful for our simulation.	All	
30.02.2023 **Raihana Shams Islam Antara**	1. Arian 2. Munyem 3. Sajid	Discussed simulation for 3 approaches in proteus.		To provide a slide mentioning the best softwares and hardware statistics
02.03.2023	All	Progress Presentation	All	To work on our individual circuits.
29.03.2023 **Nahid Hossain Taz**	1. Arian 2. Munyem 3. Sajid	Consultation on how to update our charging and battery circuit in matlab.		
30.03.2023	All	Task1: Try to connect all the individual circuits to make a proper simulation. Task2: make charging circuit on matlab Task3: make piezoelectric equivalent circuit on matlab Task4: alternative sources of oceanic wave for in current source on matlab Approach 3	Task1: Arian Task2: Sajid Task3: Munyem Task4: Maher	

03.04.2023	All	Meeting on correcting the error parts.		
05.04.202	1. Arian 2. Munyem 3. Sajid	Task1: Build a almost over all circuit Task2: make 3D objects for visualization the full concept Task3: find some practical data for building up the circuit	Task1: Arian Task2: Sajid Task3: Munyem	
08.04.2023 **Nahid Hossain Taz**	1. Arian 2. Munyem 3. Sajid	Presentation on the project with the three approaches simulation part.		Suggested to do practical citation for our simulation
10.04.2023 **Raihana Shams Islam Antara**	1. Arian 2. Munyem 3. Sajid	Presentation on the project with the three approaches with 3D objects and simulations.		
12.04.2023	All	Make a piezoelectric calculator for practical data in formation.		
13.04.2023	All	Complete simulations and discussed with the errors.		
15.04.2023	All	Editing the whole Project with proper simulation and 3D objects for proper visualization.		
16.03.2023	All	Organization all the paper		
17.04.2023	All	Final touch and submitted		

FYDP (C) SUMMER 23 Summary of Team Log Book / Journal

Date/Time/ Place	Attendance	Summary of Meeting Minutes	Responsible	Comment by ATC
01.06.2023	All	Introductory discussion about Hardware.	All	
4.06.2023 **Nahid Hossain Taz**	1. Arian 2. Munyem 3. Sajid	Selected components..	All	
8.06.2023 **Raihana Shams Islam Antara**	All	.Discussed on the hardware design such as circuit design and proto type design	All	Suggested how to design our hardware part
13.06.2023 **Dr. A.S. Nazmul Huda**	All	Discussed on piezoelectric devices wire connection.	All	Suggested methods to select the best components
16.06.2023 **Dr. A.S. Nazmul Huda**	All	Presented some component testing parts of our proto type.	All	Suggested to work more on a specific problem in the hardware circuit.
01.07.2022	1. Arian 2. Munyem 3. Sajid	Meeting on selected components and to study on the selected project to collect some data which is useful for our hardware design.	All	
07.07.2023 **Raihana Shams Islam Antara**	1. Arian 2. Munyem 3. Sajid	Discussed about output voltage from piezoelectric disk..		SuggestedTo mention the output data .
12.07.2023	All	Progress Presentation	All	
16.07.2023 **Nahid Hossain Taz**	1. Arian 2. Munyem 3. Sajid	Consultation on how to solve our charging and battery circuit..		
20.07.2023	All	Task1: Try to connect all the individual circuits to get proper output. Task2: make a charging circuit . Task3: make piezoelectric stack on a board. Task4: make speed breaker slope design.	Task1: Arian Task2: Sajid Task3: Munyem Task4: Maher	To work on our individual circuits.
23.07.2023	All	Meeting on correcting the error parts.		
29.07.2023	1. Arian 2. Munyem 3. Sajid	Task1: Build a almost over all circuit Task2: make speed breaker with proper specifications.	Task1: Arian Task2: Sajid Task3: Munyem	

		Task3: take some practical data from our almost complete project and make a video.		
8.08.2023 **Dr. A.S. Nazmul Huda** **Nahid Hossain Taz** **Raihana Shams Islam Antara**	All	Show the complete design project.		
16.08.2023 **Nahid Hossain Taz**	1. Arian 2. Munyem 3. Sajid	Update our previous piezoelectric calculator for practical data in formation.		Suggested to do more practical visualization.
26.08.2023	All	Poster Presentation and FYDP project showcase with the final complete proto type of our design project.		
29.08.2023 **Dr. A.S. Nazmul Huda**	1.Arian 2.Munyem 3. Sajid	Draft report preparing		Suggested to editing and submit properly.Also clear out doubt about write up
8.09.2023	All	Editing the whole Project with proper practical data from our design project and 3D objects for proper visualization.		
12.09.2023	All	Organization all the paper		
17.09.2023	All	Final touch and submitted		

Related codes

Code for piezo calculator,

HTML(index.html):

```
<!DOCTYPE html>
<html lang="en">
<head>
   <meta charset="UTF-8">
   <meta http-equiv="X-UA-Compatible" content="IE=edge">
   <meta name="viewport" content="width=device-width, initial-scale=1.0">
   <link rel="stylesheet" href="./style.css">
   <title>Calculation</title>
</head>
<body>
  <div class="card">
   <h2 class="header-line">Piezo Calculator</h3>
       <div class="cart-sub">
           <div>
               <label for="input1">Length:</label>
               <input type="text" id="input1">  ft
           </div>
           <div>
               <label for="input2">Breadth:</label>
               <input type="text" id="input2">  ft
           </div>
           <div>
               <label for="input3">Mass:</label>
               <input type="text" id="input3">  kg
           </div>
           <div><button onclick="calculate()">Calculate</button></div>
           <br><br>
           <div class="Result">
               <label for="output1">Total Piezo:</label>
               <span id="output1"></span><br>
               <label for="output2">Piezo in series:</label>
               <span id="output2"></span><br>
               <label for="output3">Piezo in parallel:</label>
               <span id="output3"></span><br>
               <label for="output4">Voltage:</label>
               <span id="output4"></span><br>
               <label for="output5">Current:</label>
               <span id="output5"></span><br>
```

```
            </div>
        </div>
   </div>

   <script src="./index.js"></script>
</body>
</html>
```

CSS(style.css)

```
.card{
   background-color: rgb(221, 208, 208);
   width: 400px;
   height: 450px;
   margin: 100px auto;
   padding: 20px;
   border-radius: 10px;
}
.header-line{
    text-align: center;
}
.Result{
    font-size: 20px;
    font-weight: 600;
}

.cart-sub{
    text-align: center;
}

.cart-sub div{
    margin-bottom: 10px;
}

.cart-sub input{
    padding: 5px;
}
button{
    background-color: #4CAF50;
    color: white;
    padding: 12px 24px;
    border: none;
    border-radius: 4px;
    margin-top: 20px;
```

```
   cursor: pointer;
}
```

Javascript(index.js)

```
function calculate() {
   // get input values
   const input1 = parseFloat(document.getElementById("input1").value);
   const input2 = parseFloat(document.getElementById("input2").value);
   const input3 = parseFloat(document.getElementById("input3").value);

   // perform calculations and set output values
   const output1 = (input1*6)*(input2*8)
   const output2 = input1*6
   const output3 = input2*8
   const output4 = input1*6*3.5
   const output5 = input2*8*0.02
   // display output values
   document.getElementById("output1").textContent = output1;
   document.getElementById("output2").textContent = output2;
   document.getElementById("output3").textContent = output3;
   document.getElementById("output4").textContent = output4 +"V";
   document.getElementById("output5").textContent = output5 +"A";

   // document.getElementById("input1").value = " ";
   // document.getElementById("input2").value = " ";
   // document.getElementById("input3").value = " ";
   // document.getElementById("input4").value = " ";
   // document.getElementById("input5").value = " ";

  }
```

Code for Vehicle (controlled with Bluetooth):

```
int lsrpwm=6; //left side forward
int lslpwm=5;// left side backward
int rsrpwm=10;//right forward
int rslpwm=9;// right backward

char val;

void setup()
{

pinMode(2, OUTPUT); //R-left en
```

```
pinMode(3, OUTPUT); //R-Right en
pinMode(7, OUTPUT); //L-Right en
pinMode(8, OUTPUT); //L-Left en
pinMode(lslpwm, OUTPUT); // L-Lpwm
pinMode(lsrpwm, OUTPUT); // l-Rpwm
pinMode(rslpwm, OUTPUT); // R-Lpwm
pinMode(rsrpwm, OUTPUT); //R-Rpwm

Serial.begin(9600);
}
void loop()
{
 if (Serial.available() > 0)
 {
 val = Serial.read();
 Serial.println(val);
 }
 if( val == 'B') // Back
  {
   digitalWrite(2, HIGH);
   digitalWrite(3, HIGH);
   digitalWrite(7, HIGH);
   digitalWrite(8, HIGH);

   analogWrite(lsrpwm, 0);
   analogWrite(lslpwm, 255);//
   analogWrite(rslpwm, 255);
   analogWrite(rsrpwm,0);
  }
  if( val == 'F') // Forward
  {
   digitalWrite(2, HIGH);
   digitalWrite(3, HIGH);
   digitalWrite(7, HIGH);
   digitalWrite(8, HIGH);

   analogWrite(lsrpwm, 255);
   analogWrite(lslpwm, 0);
   analogWrite(rslpwm, 0);
   analogWrite(rsrpwm,255);
  }
  if( val == 'R') // Right
  {
  digitalWrite(2, HIGH);
```

```
  digitalWrite(3, HIGH);
  digitalWrite(7, HIGH);
  digitalWrite(8, HIGH);

  analogWrite(lsrpwm, 230);
  analogWrite(lslpwm, 0);
  analogWrite(rslpwm, 250);
  analogWrite(rsrpwm,0);
}
if( val == 'L') // Left

{  digitalWrite(2, HIGH);
  digitalWrite(3, HIGH);
  digitalWrite(7, HIGH);
  digitalWrite(8, HIGH);

  analogWrite(lsrpwm, 0);
  analogWrite(lslpwm, 250);
  analogWrite(rslpwm, 0);
  analogWrite(rsrpwm,250);
}
if( val == 'I') // Fwd Right
{
  digitalWrite(2, HIGH);
  digitalWrite(3, HIGH);
  digitalWrite(7, HIGH);
  digitalWrite(8, HIGH);

  analogWrite(lsrpwm, 250);
  analogWrite(lslpwm, 0);
  analogWrite(rslpwm,0);
  analogWrite(rsrpwm,80);
}
if( val == 'G') // Fwd Left
{
    digitalWrite(2, HIGH);
  digitalWrite(3, HIGH);
  digitalWrite(7, HIGH);
  digitalWrite(8, HIGH);

  analogWrite(lsrpwm, 80);
  analogWrite(lslpwm, 0);
  analogWrite(rslpwm, 0);
  analogWrite(rsrpwm,250);
```

```
}
if( val == 'H') // Back Left
{
     digitalWrite(2, HIGH);
  digitalWrite(3, HIGH);
  digitalWrite(7, HIGH);
  digitalWrite(8, HIGH);

  analogWrite(lsrpwm, 0);
  analogWrite(lslpwm, 80);
  analogWrite(rslpwm,250);
  analogWrite(rsrpwm,0);

}
if( val == 'J') // Back Right
{
   digitalWrite(2, HIGH);
  digitalWrite(3, HIGH);
  digitalWrite(7, HIGH);
  digitalWrite(8, HIGH);

  analogWrite(lsrpwm, 0);
  analogWrite(lslpwm, 250);
  analogWrite(rslpwm, 80);
  analogWrite(rsrpwm,0);

}
 if( val == 'S') // Stop
{
     digitalWrite(2, HIGH);
  digitalWrite(3, HIGH);
  digitalWrite(7, HIGH);
  digitalWrite(8, HIGH);

  analogWrite(lsrpwm, 0);
  analogWrite(lslpwm, 0);
  analogWrite(rslpwm, 0);
  analogWrite(rsrpwm, 0);
}
}
```