ANALYSIS OF PIEZO ENERGY HARVESTING SYSTEM USING A SINGLE CANTILEVER BEAM (SCB) IN WINDCATCHERS

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ANALYSIS OF PIEZO ENERGY HARVESTING SYSTEM USING A SINGLE CANTILEVER BEAM (SCB) IN WINDCATCHERS.

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This report is submitted in partial fulfilment of the requirements for the degree of Bachelor of Electronic Engineering with Honours

Faculty of Electronic and Computer Engineering and Technology
Universiti Teknikal Malaysia Melaka

2024

UNIVERSITI TEKNIKAL MALAYSIA MELAKA
FAKULTI TEKNOLOGI DAN KEJURUTERAAN ELEKTRONIK DAN KOMPUTER

BORANG PENGESAHAN STATUS LAPORAN
PROJEK SARJANA MUDA II

Tajuk Projek : Analysis of piezo energy harvesting system using a single cantilever beam (SCB) inwindcatchers.

Sesi Pengajian : 2023/2024

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DEDICATION

To my parents, Zainab Binti Mustafa and Adzmi Bin Ibrahim who always support me. To my family members and fellow friends.

ABSTRACT

In the world where the effect of conventional energy source such as coal and fossil fuel has become the main concern by the earth population, extensive research has been conducted on various renewable energy alternatives, with some of them showing promising potential for the future. Consequently, there is an increasing demand for exploring new clean energy sources, leading to extensive research in this field. Among the explored energy sources, wind power has received significant attention. Nevertheless, traditional wind turbines require high wind speeds, limiting their deployment to specific locations. To address this limitation, this project proposes a novel approach: designing a windcatcher utilizing a single cantilever beam for a piezo energy harvesting system. The primary objective is to design the windcatcher using single cantilever beam for the piezo energy harvesting system, to design a data collection monitoring system for piezo energy harvesting and to analyse the output voltage of different windcatcher designs as innovative piezoelectric harvesters (PEHs). The windcatchers will be specifically designed to capture energy from the induced airflow generated by moving vehicles on roads, highways, and streets. Subsequently, the prototypes were created and subjected to rigorous testing to test the feasibility of this methods. Then, this design has been tested in the lab. At the end of

the project, a functional piezoelectric harvester was be developed. Overall, this project is success, and the research aims to explore new avenues in energy harvesting by utilizing the windcatcher design and developing efficient piezoelectric harvesters capable of capitalizing on induced airflow from ground vehicles are achieved. Despite this project nature as a proof of concept, this research has successfully developed a piezoelectric harvester with the max generated voltage is 3.3V.

ABSTRAK

Di dunia di mana kesan sumber tenaga konvensional seperti batu arang dan bahan api fosil telah menjadi kebimbangan utama oleh penduduk bumi, penyelidikan meluas telah dijalankan untuk mencari pelbagai alternatif tenaga bolehbaharu, di mana beberapa daripadanya menunjukkan potensi yang menjanjikan untuk masa depan. Akibatnya, terdapat permintaan yang meningkat untuk menerokai sumber tenaga bersih baharu, yang mendorong penyelidikan yang meluas dalam bidang ini. Antara sumber tenaga yang telah diselidik, kuasa angin menerima perhatian yang besar. Walau bagaimanapun, turbin angin tradisional memerlukan kelajuan angin yang tinggi, membataskan penempatan mereka hanya di lokasi tertentu. Bagi mengatasi had ini, projek ini mencadangkan pendekatan baharu: reka bentuk pengumpul angin yang menggunakan struktur tunggal berengsel sebagai sistem penjana tenaga piezo. Objektif utama projek ini adalah untuk mereka bentuk penangkap angin menggunakan struktur Tunggal berengsel untuk sistem penjana tenaga piezo, mereka bentuk sistem pemantauan pengumpulan data untuk penjana tenaga piezo dan u menganalisis voltan yang dihasilkan oleh plebagai reka bentuk penangkap angin yang berbeza sebagai penuai piezoelektrik yang inovatif. Penangkap angin akan direka khusus untuk menangkap tenaga daripada aliran udara yang dihasilkan oleh kenderaan yang *bergerak di jalan raya, lebuh raya dan jalan raya. Selepas itu, prototaip telah dicipta dan tertakluk kepada ujian yang ketat untuk menguji kebolehlaksanaan kaedah ini. Kemudian, reka bentuk ini telah diuji di makmal. Pada akhir projek, penuai piezoelektrik berfungsi telah dibina. Secara keseluruhannya, projek ini berjaya, dan penyelidikan bertujuan untuk meneroka jalan baharu dalam penjanaan tenaga dengan menggunakan reka bentuk penangkap angin dan membangunkan penjana piezoelektrik yang cekap yang mampu memanfaatkan aliran udara daripada kenderaan darat dicapai. Walaupun sifat projek ini sebagai pembukti konsep, penyelidikan ini telah berjaya membangunkan penjana piezoelektrik dengan hasil janaan maksima 3.3V.*

ACKNOWLEDGEMENTS

The opportunity I had during this final year degree project was a great chance for learning development. Hence, I consider myself to be lucky to be part of it. I am honored for having a chance to meet so many wonderful people and professionals who led me through this project period. Firstly, I am grateful to Almighty God for keeping me physically and mentally well.

Next, I would like to express my deepest gratitude to my degree project supervisors, Dr Khairun Nisa binti Khamil. She has provided me with a lot of guidance, ideas and comments throughout the project process which were extremely valuable for my project both theoretically and practically. Thanks to all my lecturers, who are willing to spend their time in offering they thought and answering all questions on the matter concerning my study here, fellow friends who helps a lot and dearest parents for moral support. I perceive this semester experience as an opportunity to gain skills and knowledge in the best possible way. And I will continue to work on constant improvement, in order to attain desired career objectives in future.

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LIST OF SYMBOLS AND ABBREVIATIONS

PEH	:	Piezoelectric energy harvester
DC	:	Direct Current
AC	:	Alternate Current
USB	:	Universal Serial Bus
IOT	:	Internet Of Things

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CHAPTER 1

INTRODUCTION

In this chapter, introduction to general area of study will be discussed, which is piezoelectric energy harvester, brief review of the state of knowledge in the involved area, indication of gap short coming of previous research, the aims of this project, and the scopes of project.

1.1 Background of The Project/Motivation

At the moment, fossil fuels like coal and gas, which are limited resources, are the main sources of the world's energy. This energy source has been slowly getting less abundant; it is just a matter of time before it runs out. These are concerning because the world's transformation into the digital era resulted in higher-than-ever electrical demand. Numerous different energies harvesting techniques and energy sources were investigated to address this issue. Wind was one of the energy sources that was frequently investigated.

The conventional wind turbine, however, needed strong winds in order to operate. Additionally, only specific locations could use these wind turbines due to the requirement for high wind speed. can have an impact on wildlife, especially birds. It has been demonstrated that a number of factors, including the placement of wind turbines, the species of birds, and environmental factors, contribute to bird death[1].

The windcatcher design for this project was influenced by Vortex bladeless wind turbines (VBWTs), which have been successfully proved to scavenge wind energy [2]. The absence of revolving blades or other moving components, as the name suggests, is one of this type of turbine's key characteristics. As a result, they are viewed as an affordable, effective, and ecologically friendly substitute for conventional propeller-type turbines [3]. VBWTs have a wider working range and a higher power density than horizontal and vertical axis wind turbines because they can produce power at lower wind speeds.

The energy source for this project is piezoelectric. The use of a crystal or other material that may generate electrical energy—adverse current and voltage—by accepting mechanical energy, such as vibration or pressure, is how a piezoelectric device operates [4]. Piezo energy harvesting's precision and efficiency are still being investigated because of how widely they can differ. Data investigation revealed that Kuala Lumpur vehicle motion created a constant and continuous source of airflow (wind) that ranged from 2 to 4 m/s [5]. This wind speed was measured on Malaysian roads. There are a number of methods for collecting piezo energy that have been discovered and researched.

1.2 Project Summary

One of the energy sources that was often explored is wind. However, the wind turbine that was used required high wind speed. Additionally, due to the need for high wind speed, only certain locations could deploy these wind turbines. Therefore, this project proposes to design the windcatcher using a single cantilever beam for the piezo energy harvesting system. These windcatchers will be designed to harvest energy from induced airflow generated by cruising ground vehicles on the road, highway, or streets. Then, this design will be tested by making a prototype. Additionally, to analyze the output voltage from each of the windcatcher designs of the new PEHs, a data collection system was developed. The microcontroller esp32 nodeMCU will be used to obtain the data from the piezoelectric windcatcher. At the end of the project, the functional piezoelectric harvester would be developed.

1.3 Problem Statement

This piezoelectric windcatcher has a simple structure and is easy to fabricate compared with other wind power generators such as conventional wind turbines. A typical piezoelectric energy harvester based on mechanical vibration can achieve maximum output power when its mass oscillates at its resonant frequency. However, the resonant frequency is commonly too high to be able to harvest energy from ambient vibration or human motion at low frequency. (Sung Kwon. D et, al 2014, Seok Yun. J et, al 2011) [6][7]. There is yet research on using windcatcher to create energy on the roadside using wind generated by car to excite piezoelectric element.

The piezoelectric windcatcher is utilizing physical movement. However, to make efficient use of the piezoelectric material, usually, the active vibration control applications to produce vibration close to the resonant frequency are prioritize, but the effects of the placement are also important, but this problem has received little attention in comparison (V. Gupta et, al 2010) [8][9]. There is yet to be research on piezoelectric placement for windcatcher.

1.4 Objective

i. To design the windcatcher using single cantilever beam for the piezo energy harvesting system.

ii. To design a data collection monitoring system for piezo energy harvesting.

iii. To analyze the output voltage from the designed windcatcher.

1.5 Scope of Project

This project is divided into two parts, the aim of PSM 1 is to develop and analyze a piezo energy harvester at roadway which will use esp32 nodeMCU and ThingSpeak to store the collected data. Before the output is stored sensoringSpeak website, the adc pin will act as voltage sensor is functional to monitor the voltages and current input that was generated by the piezoelectric element. The data collection system introduced in this project aims to give a reliable method of data collection with minimal equipment as large equipment such as laptop could be a hindrance during data collection. Additionally, if anything were to happen to the system the data are safely transferred to ThingSpeak for storage.

For PSM 2, the PEH design which consists of six piezoelectric transducer plates that will detect the vibration energy when surrounding wind push the windcatcher will be investigated. The output that receives from piezo will be transferred to a rectifier that converts ac current to dc current. Then, the esp32 nodeMCU will measure generated voltage and transfer it into ThingSpeak for analysis.

1.6 Thesis Outline

The Piezo Energy Harvesting System was created to look into the piezoelectric potential as a power source. To make the project's specifics easier to understand, they were separated into chapters. The focus of each chapter of this report is displayed as follows.

Chapter 1: An overview of the project will be provided in this chapter. provides a fundamental overview of the subject and explains the terminologies and underlying information. This chapter provides a detailed explanation of the problem statement, objectives, scopes, value of study, and the outline for each step during the entire project.

Chapter 2: The research that was carried out to comprehend the project more fully will be covered in this chapter. The background study comprises a thorough analysis of the location, prior research on the topic, pertinent historical information about the situation, and current events surrounding the problem. The websites, research papers, books, articles, and some electronic reference books used in this project served as the sources for this study.

Chapter 3: The steps and methods utilized to produce the project's results will be covered in this chapter, along with a description of the hardware and software employed. The design of the piezo energy harvesting system requires the use of several phases. In this chapter, the piezoelectric energy harvesting system's electronics and data collection tools were thoroughly explained. Everything you needed to know about the project's overall flow was covered in this chapter.

Chapter 4: This chapter will discuss the results and discoveries made throughout the development of the thing project over the course of the semester. Additionally, the project's theory and/or simulation will be compared to the results. The interpretation and explanation of the piezoelectric energy harvesting system's output, as well as a critical assessment of the system's statistics, are included in the discussion section.

Chapter 5: In this chapter the project findings will be discussed and summarized. It will also describe the conclusion of this project. Other than that, this chapter will also discuss the further improvements that can be made to the project to improve it and its potential usage in other projects or system.

CHAPTER 2

BACKGROUND STUDY

In this chapter, the research and studies on the previous paper and material that is relevant to the project will be discussed. Additionally, the primary objective of conducting a literature review is not just to summarize the earlier research but also to critically evaluate the research that is relevant to our issue and then present it from a different perspective.

2.1 Theory

2.1.1 History

Brothers Paul-Jacques and Pierre Curie, two French physicists, discovered the fascinating piezoelectric action in tourmaline, quartz, and Rochelle salt crystals in 1880. (Potassium sodium tartrate). They discovered, after testing a variety of crystals, that applying mechanical pressure to certain crystals, such as quartz, caused an electrical charge to be released. The piezoelectric effect was used to describe this. The word "press" in the Greek word piezein is where they got their name from. In an article published in 1889's Annales de Chimie et de Physique, Jacques summarized the observation: "Equal amounts of electricity of opposing signs, proportional to the acting force and independent of the dimensions of the quartz, occur at the extremities of this axis if one pulls or squeezes along the main axis.".[9]

The following year, they saw the opposite result in 1881, Gabriel Lippman theorized that the application of an electric field to certain materials would cause internal mechanical strains, which was the opposite effect of what the Curies discovered in 1880. However, the Curies quickly conducted experiments and found that Lippman's prediction was incorrect, and that their initial discovery of the piezoelectric effect was correct. [9]

For the first 30 years following the discovery of the piezoelectric effect, it was mainly used in laboratory experiments and further research. However, during World War I, French physicist Paul Langevin put it to practical use in sonar technology by applying voltage to a piezoelectric transmitter. This is an example of the inverse piezoelectric effect, which converts electrical energy into mechanical sound waves.[9]

The success of using piezoelectricity in sonar technology during World War I caught the attention of the military, and during World War II, researchers from the United States, Russia, and Japan worked to create new man-made piezoelectric materials, known as ferroelectrics. This research resulted in the development of two new materials, lead zirconate and barium titanate, which were used in addition to natural quartz crystal.[9]

2.1.2 Working Principle

Piezoelectricity is a phenomenon where a voltage is generated across a crystal when mechanical stress is applied to it. This effect is known as the piezoelectric effect, and it comes from the Greek word "piezein" which means to press or squeeze. In this process, the crystal acts like a battery, with a positive charge on one face and a negative charge on the other. This creates a current flow when the two faces are connected in a circuit. On the other hand, the reverse piezoelectric effect is when a crystal is deformed in shape when a voltage is applied across its opposite faces.[9]

Crystals are defined as a solid whose atoms or molecules are orderly arranged based on repeating unit cells, however, the unit cell in piezoelectric crystals is not symmetrical. These crystals electrically are normally neutral, but when mechanical stress is applied it causes a deformation which creates an imbalance of negative and positive charges, causing the total electrical charges to appear on the opposite outer faces of the crystal.[9]

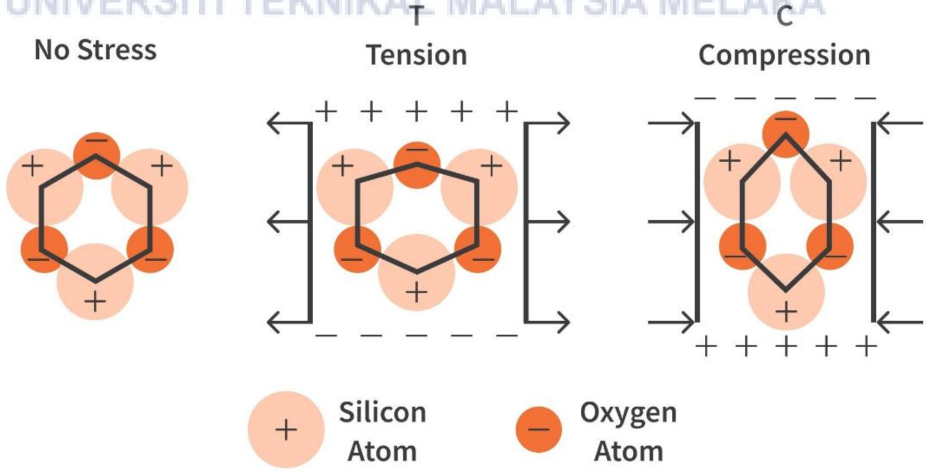

Figure 2.1: piezoelectric effect[10]

The reverse-piezoelectric effect is the opposite of the regular piezoelectric effect, which is when a voltage is applied across a piezoelectric crystal, it creates an "electrical pressure" on the atoms inside it which causes them to move and rebalance themselves. This results in the crystal deforming or changing shape slightly when voltage is applied across it. [9]

2.1.3 Piezoelectric Equation

A unidimensional piezoelectric material can be represented by a constitutive equation, which combines the electrical induction (D), electric field (E), strain (S), and stress (T). Additionally, based on the principle of energy conservation, at low frequencies the equation is:[11]

$$\mathrm{D} = dT + \varepsilon^T E \ldots (1)$$

$$\mathrm{S} = S^E T - d'E \ldots (2)$$

Where ε^T is the permittivity at constant stress, S^E is the compliance at constant electric field and d is the piezoelectric charge coefficient. Therefore, unlike a non-piezoelectric material, a piezoelectric material also experiences strain due to an electric field, and an electric charge due to mechanical stress (displacement of charges within the material results in opposite polarity surface charges on the plates). When the surface area does not change under the applied stress (which is not the case with polymers) which is (*d*=*d'*), then equation (1) for E and equation (2) for T can be solved to obtain:[11]

$$\mathrm{E} = \frac{D}{\varepsilon^T} - \frac{Td}{\varepsilon^T} = \frac{D}{\varepsilon^T} - gT \ldots (3)$$

$$\mathrm{T} = \frac{d}{S^E}E + \frac{1}{S^E} = C^E S - e^E \ldots (4)$$

Additionally, when an external force is applied to the piezoelectric materials (stressing) and the output voltage is measured at the terminals of the piezoelectric material, as depicted in Figure 2.2, it leads to the accumulation of an electric charge $Q_3 = D_3 Q A_3$ on the electrodes of area A_3 to yield a voltage $V_3 = Q_3/C_3$. The electric charge density is $D_3 = d_{33}T_1$, whereby $T_1 = d_{33}F_1/A_1$ and $\varepsilon_{33}^T A_3/h$. Therefore, voltage output when applying a certain force can be calculated from:[11]

$$V_3 = d_{33}F_1\left(\frac{1}{A_3}\frac{h}{\varepsilon_{33}^T}\right) \ldots (5)$$

Figure 2.2. open circuit voltage measurement set up of a piezoelectric sample when applying external mechanical force[11]

Equation 5 shows that the voltage output at the terminals of the piezoelectric material V_{33} is directly proportional to the applied force (F), assuming the other variables are constant.[11]

2.2 Literature Review

Younis. A et, al (2022) presented a design and development of bladeless vibration based piezoelectric energy–harvesting wind turbine [12]. The paper highlighted bladeless wind energy–harvesting device-based vortex-induced vibrations (VIV). The design makes use of the vortices created when airflow interacts with the mast. When this happens, the flow splits, separates, and creates vortices, which eventually cause the elastic rod to oscillate and allow energy to be gathered from them. Computational fluid dynamics (CFD) modelling and simulations were performed on the elastic mast, a VIV device's core wind energy– collecting component, to guide the device's design. These simulations examined the mast-produced lift coefficient, velocity, pressure, and vorticity contours of different mast geometries. Additionally, a scaled model in the wind tunnel was used to experimentally test the vibration energy of the mast under various wind speeds. Several piezoelectric sensors positioned on the mast were used to measure and keep an eye on the amount of converted electric power. The study that determined the appropriate mast orientation angle and the best placement for the piezoelectric sensors to capture more energy is all that is discussed in the publication. The results of the CFD simulation indicating a complicated cylinder design provides higher power were supported by the experiments. An enhanced, new VIV design with improved power generating capabilities was created using both computational and experimental data. My research will therefore concentrate on the use of piezoelectric on various windcatcher location while also investigating the storage potential.

Song. J et, al (2022) presented a piezoelectric energy harvester with double cantilever beam undergoing coupled bending-torsion vibrations by width-splitting method [13]. The paper highlighted geometrical dimensions are optimized for PEHDCB, when the maximum of output peak voltages Up max and resonance frequency difference (Δf0) between the first and second modes are chosen as optimization objectives based on orthogonal test method. However, the paper only focuses on energy harvesting efficiency of PEHDCB compared to the conventional

PEHSCB from environmental vibration with multiple-frequency excitation. Therefore, my study will focus on single cantilever piezoelectric but will explore the storage capability of the produced energy including the usability of the output voltage and current.

Abdul Kader Zilani. Md et, al (2021) presented an unconventional energy harvesting from wind velocity and VIV resonance phenomenon by using bladeless wind turbine (Blwt) [14]. In the research, a vortex-induced vibration of a bladeless wind turbine was used to showcase a wind power generation system on the coastal side. This turbine experiences a vortex-induced vibration in its body if wind flows outside the circumferential mast. A pulley is turned by the displacement of the mast with the aid of a crankshaft. Then, to generate power, a dc generator is rotated by the pulley. The paper, however, only discusses using a dc generator to produce electricity. As a result, the focus of my research will be on exploiting design elements like springs in wind catchers to generate power using piezoelectric technology.

Maftouni. N et, al (2021) presented the effect of drag force on the body frequencies and the power spectrum of a bladeless wind turbine [15]. The paper highlighted study numerically investigated the effects of the drag force on the body frequency of an oscillating bladeless wind turbine. A two-dimensional numerical simulation was performed for a cylinder with a semi-circular crossflow cross-section in two different cases. This research was conducted for both uncontrolled and controlled oscillating cylinders. The controlling process was performed using a pair of ring magnets as springs with a variable coefficient. Lastly, the cylinder's regulated and uncontrolled frequencies are investigated, and the power spectra over a range of speeds are analyzed in two conditions, namely with and without a tuning mechanism. The findings support the hypothesis that these turbines' use of a regulating system can greatly reduce oscillations and raise frequency by restricting vibration amplitude. However, the research only focuses on studying the flow field, vibration, vortex shedding, structural frequencies, and resonance phenomena as well as simulating the influence of wind drag on the bladeless wind turbine. As a result, the focus of my research will be developing a windcatcher based on the parameters examined in the paper, while also exploring the ideal piezo arrangement and energy storage capability.

Sitharthan. R et, al (2021) presented a piezoelectric energy harvester converting wind aerodynamic energy into electrical energy for microelectronic application [16]. The developed Piezoelectric Energy Harvesting Systems that were emphasized in the research indicate that they are used to power microelectronic devices. The cantilever is positioned so that it faces the stack of piezoelectric crystals. The creation of Piezoelectric Energy Harvesting Systems denotes its use in supplying power to micro-electronic gadgets. The cantilever is positioned so that it faces the stack of piezoelectric crystals. When the wind blows, the windcatcher forms a vortex that causes the cantilever to oscillate and stresses the piezoelectric crystal stack to produce electricity. The paper, however, is limited to employing a particular arrangement of the piezoelectric crystal. My research will therefore concentrate on testing the setup that will result in the maximum voltage.

Upadhyaya. S et, al (2020) presented a piezoelectric bladeless wind turbine [17]. Its operating mechanism involves making a hollow mast vibrate at a resonant frequency, which creates vortices that are then turned into electrical energy using piezoelectric sensors. The structure vibrates the least since there are fewer moving elements. Because there are fewer moving parts, there is less structural vibration and wear and tear. Because there is no moving, sharp blades, the structure also provides better safety for birds flying about. Additionally, because less space is needed, more units may be installed for huge power generation. The research, however, solely focuses on one arrangement for employing the piezoelectric crystal. My research will therefore concentrate on testing the setup that will result in the maximum voltage.

Goryachev. S. V. et, al (2019) presented use of bladeless generator in wind power [18]. The paper focused on the enhancement of wind energy harvesting equipment and the development of generator designs intended for low consumption. The focus of the research is on using the rhythmic movements of the wind throughout the day to generate electric energy. The bladeless wind turbine uses a neodymium magnet to induce current in the coil, although the paper solely focuses on systems that employ the induction principle. Therefore, the focus of my research will be on piezoelectric electricity generation. The windcatcher design will also take into account the environmental and hygienic aspects of the design.

Davang Shubham. S et, al (2018) stated a bladeless wind turbine that device that captures the energy of vortices, an aerodynamic effect that has plagued structural engineers and architects for ages (vortex shedding effect) [19]. The wind's flow alters as it passes past a fixed structure, creating a cyclical pattern of vortices. The stationary structure begins swaying once these forces become sufficiently powerful, may enter resonance with the lateral forces of the wind, and may even collapse. The research, however, solely focuses on systems that use the induction principle because a neodymium magnet is used in a bladeless wind turbine to induce current in a coil. Therefore, the focus of my research will be on piezoelectric electricity generation. The windcatcher design will also consider the environmental and hygienic aspects of the design.

Sung Kwon. D et, al (2014) presented a piezoelectric energy harvester converting strain energy into kinetic energy for extremely low frequency operation [6]. The paper covered a frequency up-conversion mechanism-based flexible energy harvester. If the strain was great enough and the input frequency had no lower limit, the harvester's output voltage was unaffected by the input frequency. The paper, however, solely focuses on evaluating the piezoelectric output voltage's frequency limit and utilizing a shaker and magnet to enhance strain. Therefore, the focus of my research will be on the use of a single cantilever piezoelectric as a source of vibration in a windcatcher.

Wu. N et, al (2013) stated a wind energy harvesting with a piezoelectric harvester which is an energy harvesting process, to determine the charge and voltage from the energy harvester, a theoretical model that takes into account the cross wind-induced vibration on the piezoelectric linked cantilever harvester is constructed [20]. Investigations are conducted on how the proof mass, the length and location of the piezoelectric patches, and the generated electric power. The work, however, solely focuses on simulation and applying a theoretical model while researching the piezo's placement and length. As a result, the prototype of the windcatcher and the storage potential of the generated energy will be the main topics of my research.

Table 2.1: Past Project Comparison

No.	paper	authors	Paper focus	Project focus

1	Design And Development of Bladeless Vibration-based Piezoelectric Energy–harvesting Wind Turbine	Younis. A et, al (2022)	The experimental study identified the ideal orientation angle of the mast and the best location for the piezoelectric sensors for harnessing more energy.	concentrate on the use of piezoelectric on various windcatcher stops while also investigating the storage potential.
2	Piezoelectric Energy Harvester with Double Cantilever Beam Undergoing Coupled Bending-torsion Vibrations by Width-splitting Method	Song. J et, al (2022)	only focuses on energy harvesting efficiency of PEHDCB compared to the conventional PEHSCB from environmental vibration with multiple-frequency excitation.	focus on single cantilever piezoelectric but will explore the capability of the produced energy including the usability of the output voltage and current.
3	Unconventional Energy Harvesting from Wind	Abdul Kader	discusses using a dc generator to	exploiting some of the design elements in wind catchers to

	Velocity And VIV Resonance Phenomenon By Using Bladeless Wind Turbine (Blwt)	Zilani. Md et, al (2021)	produce electricity.	generate power using piezoelectric technology.
4	The Effect of Drag Force On The Body Frequencies And The Power Spectrum Of A Bladeless Wind Turbine	Maftouni. N et, al (2021)	only focuses on studying the flow field, vibration, vortex shedding, structural frequencies, and resonance phenomena and simulating the influence of wind drag on the bladeless wind turbine.	developing a windcatcher based on the parameters examined in the paper and exploring the ideal piezo arrangement.
5	Piezoelectric Energy Harvester Converting Wind Aerodynamic Energy into Electrical Energy	Sitharthan. R et, al (2021)	limited to employing a particular arrangement of the piezoelectric crystal.	concentrate on testing the setup that will result in the maximum voltage.

	for Microelectronic Application			
6	Piezoelectric Bladeless Wind Turbine	Upadhyaya. S et, al (2020)	Focuses on one arrangement for employing the piezoelectric crystal.	My project will therefore concentrate on testing the setup that will result in the maximum voltage.
7	Use Of Bladeless Generator in Wind Power	Goryachev. S. V. et, al (2019)	The bladeless wind turbine uses a neodymium magnet to induce current in the coil, although the paper solely focuses on systems that employ the induction principle.	my project will be on piezoelectric electricity generation. The windcatcher design will also take into account the environmental and hygienic aspects of the design.
8	Bladeless Wind Turbine	Davang Shubham. S et, al (2018)	Focuses on systems that use the induction principle because a neodymium	My project will be on piezoelectric electricity generation. The windcatcher design

			magnet is used in a bladeless wind turbine to induce current in a coil.	will also consider the environmental and hygienic aspects of the design.
9	Piezoelectric Energy Harvester Converting Strain Energy into Kinetic Energy for Extremely Low Frequency Operation	Sung Kwon. D et, al (2014)	Focuses on evaluating the piezoelectric output voltage's frequency limit and utilizing a shaker and magnet to enhance strain.	My project will be on the use of a single cantilever for the piezoelectric as a source of vibration in a windcatcher.
10	Wind Energy Harvesting with A Piezoelectric Harvester	Wu. N et, al (2013)	Focuses on simulation and applying a theoretical model while researching the piezo's placement and length.	the prototype of the windcatcher will be the main topics of my project.

2.3 End of Chapter 2

This project seeks to explore the potential of piezoelectric for green energy technology by developing a compact, integrated wind-powered piezo energy harvesting system. Achieving this involves designing a windcatcher that combines the piezo components with a single cantilever beam. Then, create a reliable data collection and monitoring system that can track the energy gathered in real time and offer insightful information about how well the system is working. Lastly, a thorough examination of the output voltage produced by the windcatcher will be conducted, interpreting its features, effectiveness, and possibilities for enhancing the system's overall architecture and functioning. By completing these goals, a wind-powered piezo energy collecting system that is functional will be achieved.

2.4 Prelude To Next Chapter

Prior research was addressed on the subject of the study and noted knowledge gaps in the literature review chapter. The approach will be outlined in the next chapter in order to fill in these gaps and accomplish the goals of the study. The research design, sample selection, data collecting, and analysis methods that will be used in the study are all covered in the methodology chapter. The purpose of the next chapter is to present an accurate and transparent overview of the procedures used to guarantee the study's validity and reproducibility.

CHAPTER 3

METHODOLOGY

In this chapter will discuss every process or step which has been taken to complete the project. Besides, the tools and components used in this project are explained in more detail such as functions, advantages and disadvantages of components used to perform the project successfully.

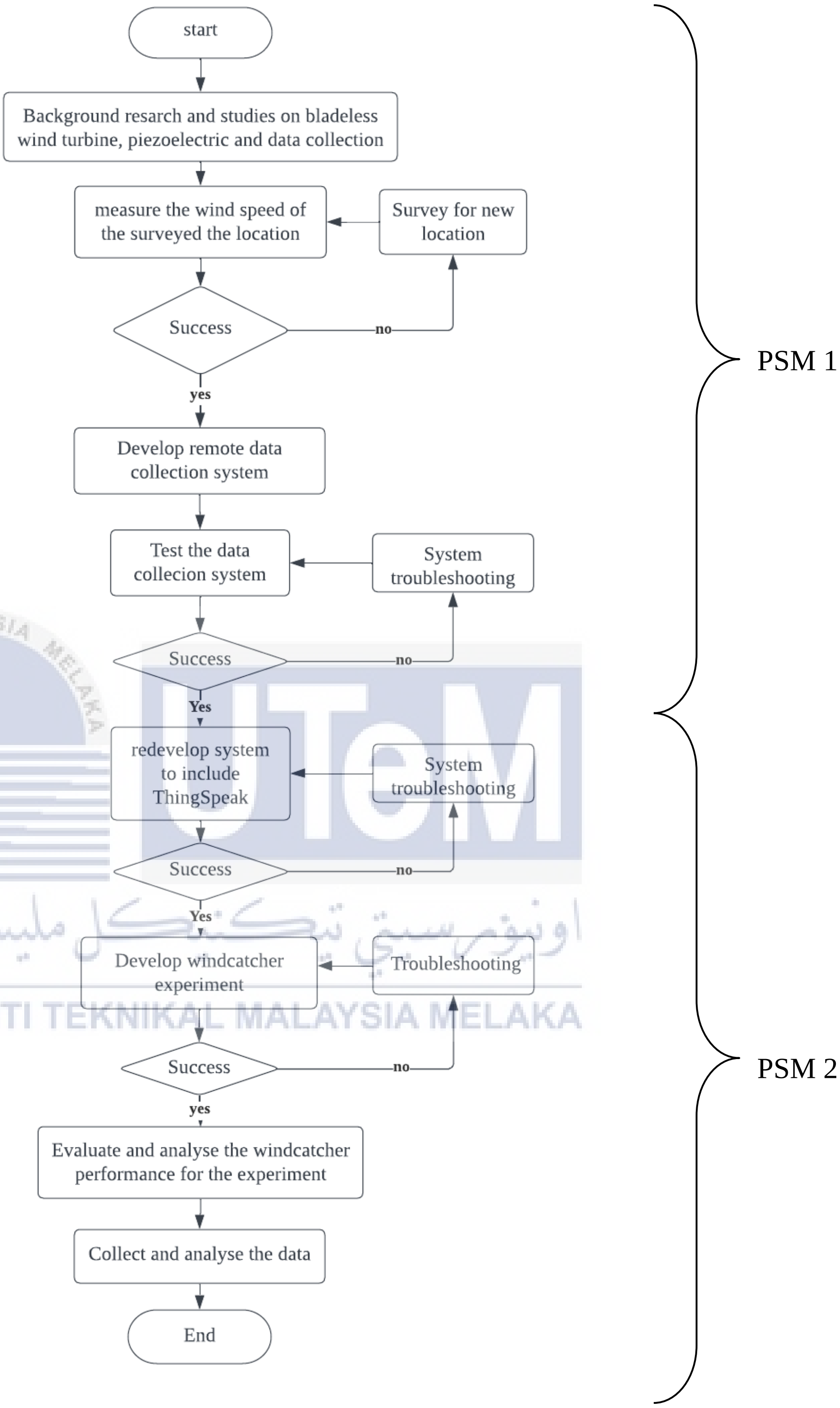

Figure 3.1: Methodology Flowchart

The methodology flowchart shown in Figure 3.1 is intended to achieve the three objectives of this project, that is divided into three main procedures. Starting by developing the single cantilever beam windcatcher. To collect the data, the project will develop a remote data collection system to store voltages value into ThingSpeak for analysis purposes. Piezoelectric energy harvester output capabilities are then evaluated. Finally, the output will be collected for analysis is performed to examine its performance and efficiency.

3.1 Background Research

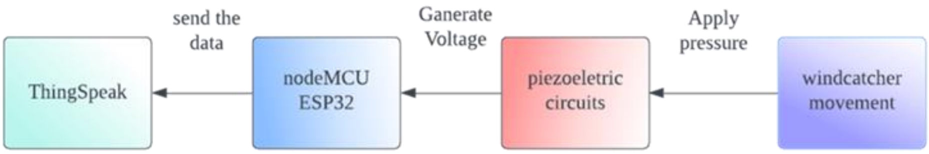

Figure 3.2: Windcatcher flowchart

For this project, there were two focuses in terms of methodology, the windcatcher and data collection circuit. To design the windcatcher, it needs to be lightweight and able to be pushed by a light wind and water resistant. A Piezo element sensor will be attached to the rod of the windcatcher to convert force energy into electrical energy. Rectifier function by converting the alternate current to direct current. For the data collection, initially the circuit was design using stm32 blue pill but later were change to esp32 NodeMCU due to its built-in Wi-Fi module. It will connect the piezoelectric circuit with ThinkSpeak via Wi-Fi. ThinkSpeak is a real-time data stream that displays data via Wi-Fi in case anything happens to esp32 NodeMCU. As shown Figure 3.2 above, the wind will push the windcatcher pedal causing it to the oscillate back and forth. The oscillation will create force that can be used to press the piezoelectric material to generate voltage. Then, the NodeMCU ESP32 will measure voltage generated using its adc port.

3.2 Data Collection System

In order to analyze the performance of piezo energy harvesting system, this research project developed a remote real-time basic design data collection system.

3.2.1 The Software

As the energy harvester and data collection system need to be designed in this project, a handful of software has been used to achieve these goals. The software that was used is Arduino IDE, and ThingSpeak.

3.2.1.1 Arduino IDE

Arduino IDE software was used to compile and upload the program code. This software was the first step in setting up the data logger system as the date and time needed to be updated every time an experiment was held. The necessary library is installed to compile the coding such as #include <WiFi.h> and #include <ThingSpeak.h>. The value of voltage will be received in the Serial Monitor of Arduino IDE software first before uploading another version of the program code that uses ThingSpeak as data storage. The display ensures its functionality and avoids the misconnection of wire from a current sensor or analog pins on the Arduino board. After verifying the device, a program code that specifically used ThingSpeak was uploaded. Here, the Serial Monitor will be opened again to ensure the board is connected to the Wi-Fi and successfully recorded the data.

3.2.1.2 ThingSpeak

IoT analytics platform service ThingSpeak offers the capacity to aggregate, visualize, and analyses live data streams in the cloud. This functionality is provided by ThingSpeak. This platform enables you to submit data from your devices to ThingSpeak in an unobtrusive manner, which in turn enables you to generate instant visualizations of real-time data. ThingSpeak uses MATLAB® analytics in order to improve its analytical capabilities. As a result, users are given the ability to easily write and run MATLAB code in order to perform preprocessing, visualizations, and analyses. Because of this one-of-a-kind integration of MATLAB within ThingSpeak, engineers and scientists now have the ability to prototype and create Internet of Things systems more quickly, without the requirement for lengthy web software development or server configuration.

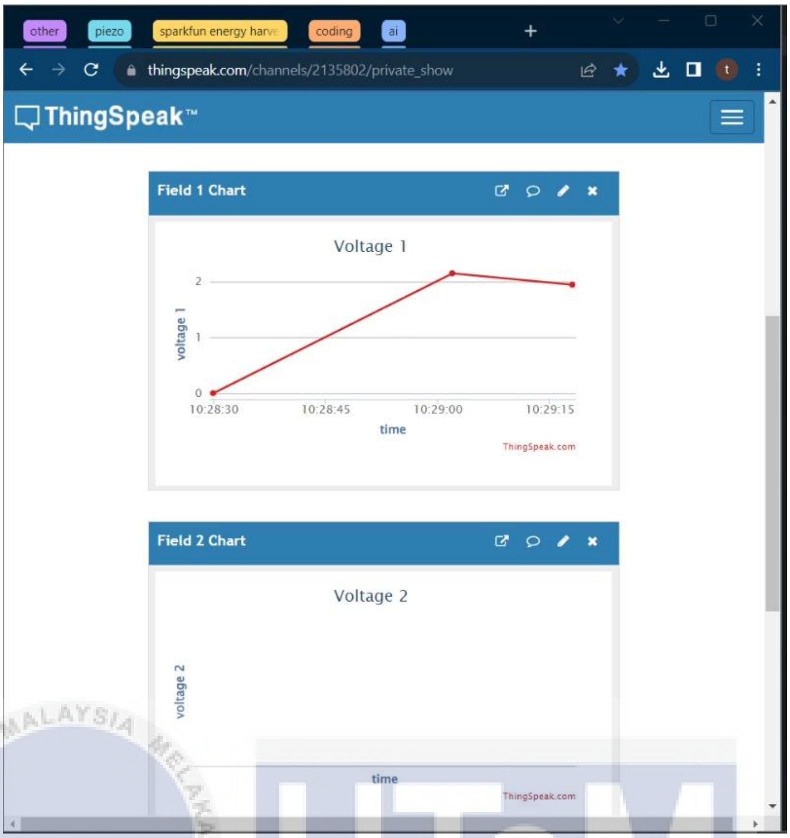

Figure 3.3: ThingSpeak interface

As shown in Figure 3.3, the interface is clean and intuitive for data analysis. Therefore, ThingSpeak is a great tool for Internet of Things practitioners because it offers these comprehensive characteristics. It does this by encouraging innovation and streamlining the process of software development.

3.2.2 The Hardware

Data collection system takes the voltage and current value of piezoelectric energy harvester. The system is controlled by a board based on the ESP-WROOM-32module, which allows data to be stored every minute and kept via internet by using wifi connection and data storing method such as ThingSpeak. The voltages value, which will be taken to analyze the energy output, together with the input and output voltage piezoelectric, were implemented by using the pins that already have been provided in the ESP-WROOM-32board. The D34 and D35 pins will be initialized as an input to connected to boost circuit to measure the generated voltage value. A0 will be used to be voltage via voltage sensor. Lastly, the ThingSpeak will be used to store the data along with time and date so that the energy produced can be analyze.

the data collection system that was proposed in this project aims to store voltage data values without any connection to a personal computer, which caused unnecessary cables while developing and experimenting with piezoelectric wind energy harvesting devices. This simple system was able to store data for an extended period of time. This data collector, also called a data logger, was implemented due to the field experiment environment, which is exposed to the element to obtain an optimum energy harvester efficiency. Thus, taking the data using a laptop and another connected device in this type of condition might hinder or disturb the air flow which could be inconvenient and impractical.

3.2.2.1 ESP32 nodeMCU

Figure 3.4: ESP32 nodeMCU

For embedded and Internet of Things (IoT) applications, the ESP32 nodeMCU microcontroller module as shown in Figure 3.4 above is a potent module. It is created by Espressif Systems, a business well known for its advancements in Bluetooth and Wi-Fi microcontroller technology. As an improved version of the ESP8266, the ESP32 nodeMCU belongs to the ESP32 family. Its foundation is the ESP32 microcontroller, a dual-core, 160–240 MHz Xtensa LX6 microprocessor. Furthermore, the module usually has a sizable quantity of RAM for data storage and Flash memory (up to several megabytes) for storing programmes. Numerous peripherals are available for the ESP-WROOM-32, including as PWM (Pulse Width Modulation), SPI (Serial Peripheral Interface), I2C (Inter-Integrated Circuit), UART (Universal Asynchronous Receiver-Transmitter), GPIO (General Purpose Input/Output) pins, and more. In addition, the ESP-WROOM-32 is supported by an active developer community, which makes it easier to adopt the platform and find solutions to issues by providing a wealth of libraries, tutorials, and example projects in an online format. This makes it suitable for IoT based project.

3.2.2.2 Rectifier

A bridge rectifier is an essential electronic circuit that converts alternating current (AC) to direct current (DC). It consists of four diodes arranged in a bridge configuration, which serve as essential process components. During the positive half-cycle of the AC input voltage, two forward-biased diodes enable the current to flow through them and reach the output's positive terminal. During the negative half-cycle, the other two diodes become forward biased, allowing current to pass through them and ultimately reach the output's negative terminal. This meticulous arrangement converts both halves of the AC input waveform into a pulsating DC output waveform, ensuring that electrical energy is transformed in a desirable manner.

Numerous power supplies and a broad variety of electronic devices employ bridge rectifiers extensively. AC-to-DC converters offer a cost-effective and efficient means of converting alternating current to direct current when used in these circumstances. Due to their ability to withstand high levels of voltage and current, bridge rectifiers have become indispensable in a variety of industries, enabling the flawless operation of electronic devices, and assuring a steady and reliable power supply.

3.2.2.3 Piezoelectric Transducer

The construction of a piezoelectric transducer varies according to its intended function, required power output, and material composition. Power harvesting applications use a variety of structures, such as the cantilever beam, circular diaphragm, cymbal transducers, and stack piezoelectric. The cantilever beams come in two varieties: the unimorph contains one piezoelectric layer, while the bimorph has two. The bimorph cantilever beam construction's power output is inversely related to its form. Finding the smallest structural volume that produces the most power is the main goal of power output estimation.

3.3 Piezoelectric Energy

3.3.1 Piezoelectric Circuit

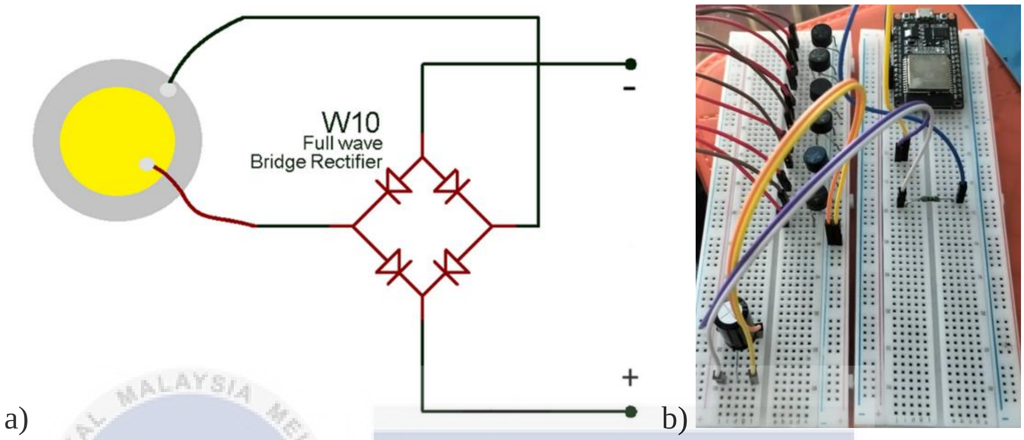

Figure 3.5: a) Piezoelectric with Rectifier b) Actual Circuit

The technology comprised of piezoelectric energy harvesting has advanced significantly however there is still some uncertainty on the design of the harvester. The installation of traditional wind turbine into the roadway divider takes up a lot of space. Thus, a small windcatcher using piezoelectric element with a 30V peak to peak voltage has been used in this project. The optimum circuit configuration of piezo element was investigated in this experiment. The circuit will consist of piezoelectric transducer connected to rectifier as shown in Figure 3.5, this is because the piezoelectric transducer generated energy in AC and DC are needed to measure the output.

3.3.2 The Windcatcher

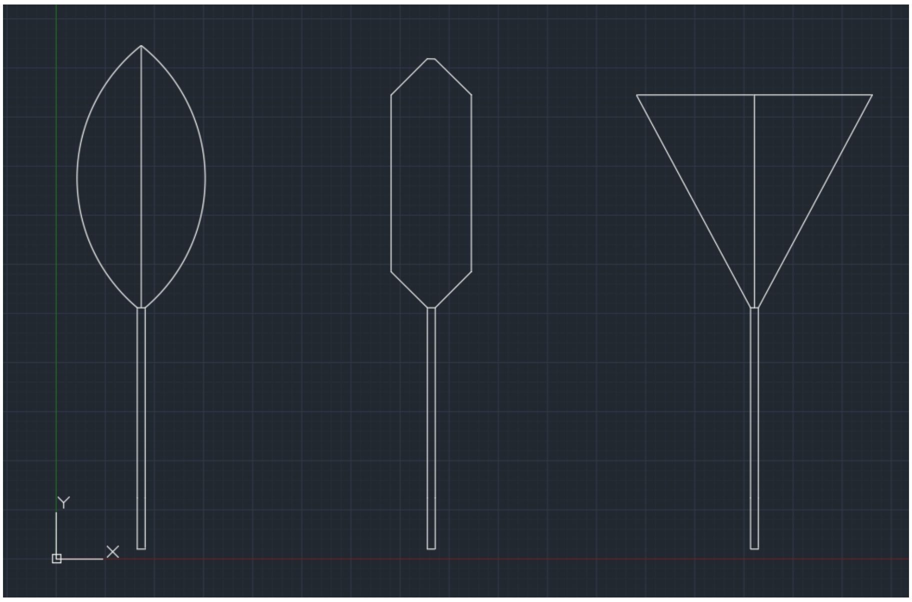

Figure 3.6 windcatcher design

This experiment utilized a similar element as the previous piezoelectric energy harvester for its configuration. For the design there were some paper that was used as the inspiration for the windcatcher design is [16] where the wind catching element is quarter circle in shape. In [21], the wind catcher design was placed on a flexible pole, and the wind catcher element have rectangular surface. Lastly, in the [22] The wind energy harvester was designed to be flexible and able to capture enough wind for rocking motion. The design of the windcatcher inspired from the previous paper is shown in Figure 3.6.

3.3.3 Boost Circuit

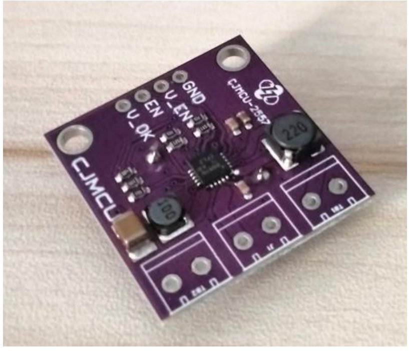

Figure 3.7 BQ25570 Boost Circuit

In this experiment, BQ25570, also called a booster charger device as shown in Figure 3.7, was used to improve the output voltage of the energy harvesting system. BQ25570 booster charger was connected, where the output voltage of the energy harvester system was taken in the VSTOR pin of the board. This device will start operating when the input voltage, Vin from the energy harvester, is obtained 0.6V. Based on the datasheet given, the voltage will be discharged when it reaches 1.8V. When charging a storage device such as a battery, 1.8V is the value where the output BQ25570 will start following the increment value of the battery. Moreover, the efficiency of this circuit is different based on the type of energy harvester is supplying, as 40% of efficiency will be the efficiency of piezoelectric harvester.

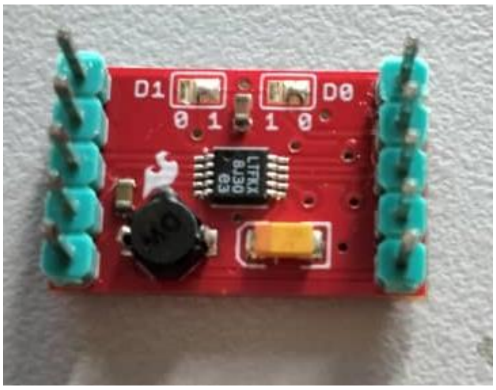

Figure 3.8: Sparkfun LTC3588 Breakout Board

The LTC3588 breakout board from SparkFun as shown in Figure 3.8 above is a flexible instrument for obtaining energy from the surroundings. It excels at exploiting piezoelectric devices to capture electricity from minute vibrations, but it can also manage other low-power sources, such as solar panels. Its ultra-low quiescent current—which means it hardly uses any power at all—makes it famous for harnessing even the weakest energy sources. After being effectively increased, this captured energy is transformed into a constant output voltage (chosen from 1.8V, 2.5V, 3.3V, and 3.6V) at a maximum current of 100mA, which is sufficient to run tiny sensors, microcontrollers, or even wireless transmitters. The SparkFun LTC3588 provides a small and easy-to-use way to convert even the smallest vibrations into useful power, whether you're making a wearable gadget that runs on its own, a remote environmental sensor, or you just want to play around with different energy sources.

3.4 Prototype Making

The materials that were used for this project is include metal rods for the cantilever, lightweight and durable materials which is metal sheet for the blades, a small electric generator circuit using the piezo and a sturdy base made out of wooden box and heavy stone for ease of experiment. The construction of the windcatcher starts by assembling it using the chosen materials. The blade shapes were cut from the chosen material, ensuring they are symmetrical. Experiment with different blade designs to find the most efficient one. Attach the blades to the cantilever and the wooden base. For this project there will be two prototypes that will be tested to see the effect of piezoelectric placement.

3.4.1 Prototype 1

Figure 3.9: Prototype 1

Figure 3.10: Piezoelectric placement prototype 1

For prototype 1, the windcatcher pedal was built using Perspex, as shown in Figure 3.9 above, the weight of 111g and surface area of 588.75cm^2. The idea is to have a light pedal so that it will be more easily blown by wind. As for the piezoelectric placement, it was placed between the cantilever and the wooden base so that the pressure between it will cause the piezoelectric element to generate voltage as shown in Figure 3.10 above.

3.4.2 Prototype 2

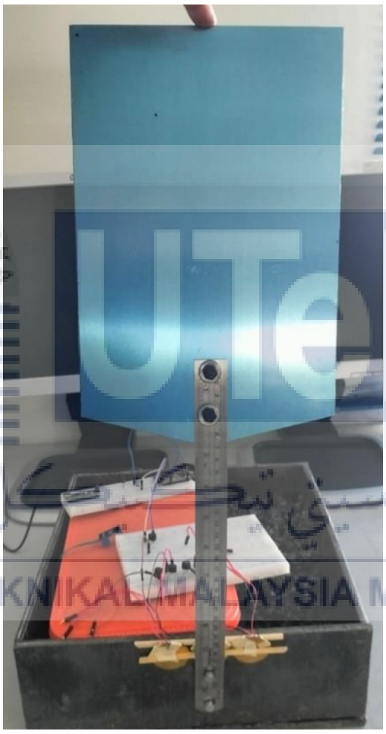

Figure 3.11: Prototype 2

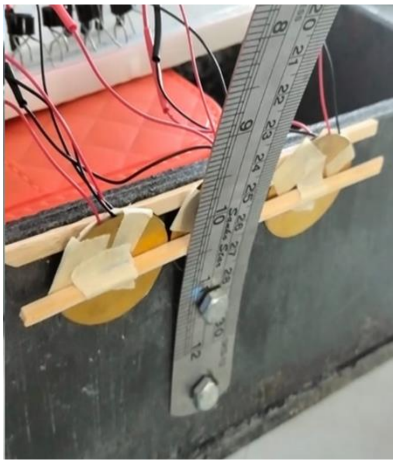

Figure 3.12: Piezoelectric placement prototype 2

For prototype 2, the windcatcher pedal was built using aluminum with the weight of 188g and surface area of 588.75cm^2 to increase the pedal strength as shown in Figure 3.11 above. As for the piezoelectric placement, to increase pressure on the piezoelectric, a grove was made to place the piezoelectric element with a wooden rod across the piezoelectric element as a uniform way to press the piezo as shown in Figure 3.12 above.

3.5 Experimentation

With the success of the fabrication, a prototype has been designed and built to suit the main purpose of the project. The device is constructed out of wooden box where the box is filled with the circuit that that was used to generate energy and collect data that is transferred via internet to ThingSpeak. The prototype will undergo several experiments and tests to ensure that it functions as intended and to see its performance. There will be 2 parts to the experiment the survey and indoor experiments.

3.5.1 Wind Speed Reading

When doing a site evaluation for the generation of wind energy or the installation of windcatchers, the wind speed is an essential factor to take into consideration. When searching for a location suitable for wind energy production, it is important to take into account a variety of factors, including the topography of the land, the presence of obstacles (such as tall buildings or trees), and the proximity of the potential location to power transmission lines. All of these factors can have an effect on how efficiently a wind-powered energy harvester works. The optimal location for a wind turbine is often one that receives a constant and consistent supply of wind energy. A location with high wind speeds will create more energy than a location with a stable wind speed because the wind energy harvester will be able to produce power continuously in the location with the steady wind speed. Taking these readings is important so that similar windspeed can be replicated for indoor experiments.

Figure 3.13: Testo 410 i anemometer[23]

An anemometer, which is a tool for measuring wind speed, can be used to determine the wind speed at a certain place. For this project, Testo 410 i vane anemometer as shown in the Figure 3.13 was used to measure the wind speed. It has the Bluetooth connection feature that will connect the anemometer to an app so the wind speed can be recorded. The characteristic for potential survey location is that it would have high traffic activity.

3.5.2 Different Circuit Configuration

For this project 6 piezoelectric elements were used for this windcatcher, due to this, the next step is to figure out which configuration is better for the circuit, series or parallel connection. Both of the prototype will be tested to see if the circuit configuration is in relation to the piezoelectric placement.

3.5.3 Fan position

To replicate the wind generated on the roadside, we will use various fan placements for simulation. These placements include the front, at a 45-degree angle from the front, from the side, at a 45-degree angle from the back, and at the back. To save time, the best circuit configuration from the previous test will be used.

3.5.4 Boost Circuit Compatibility

After the test of the previous topic, the prototype circuit will be tested using a capacitor and 2 boost circuit in order to stabilize the output voltage. The capacitors are 100µ farad capacitors while the circuit is bq25570 and ltc3588. The boost circuit functions by storing the excess energy and then used to stabilize the output when the input fluctuates around the input threshold.

3.6 End of Chapter 3

This research study compares circuit configurations, analyses wind speed data, and examines boost circuit compatibility in order to assess the efficacy of a piezoelectric wind harvester. In order to determine the wind speed and provide information for the design parameters of the harvester interior experiment, a thorough wind speed survey will first be carried out along the designated road. To find the best configuration for voltage generation, two prototypes with two circuits—series and parallel—will be constructed and tested concurrently with the different locations of the piezoelectric elements. Ultimately, the selected circuit will be combined with two boost circuit models (bq25570 and ltc3588) and 100µF capacitors to test how well they stabilize the output voltage in the presence of varying wind conditions.

3.7 Prelude to next chapter

The study's research design, sample selection, data collection, and analysis methods have been described in the methodology chapter. The study's results will be presented and discussed in the next chapter in connection with the study's goals. A thorough study of the data will follow the presentation of the primary findings. An interpretation of the results, emphasizing their importance and consequences, will be provided in the discussion chapter. Additionally, we will make comparisons with the results of earlier study and consider any research constraints or limitations. A thorough grasp of the study's findings and their ramifications for the larger field will be provided in the next chapter.

CHAPTER 4

RESULTS AND DISCUSSION

This chapter will examine the results acquired from the data collection system, which will be related to the theoretical information and comparison with previous research. This section will also provide an in-depth discussion on how each method will affect the data.

4.1 Outdoor Experiment

For the outdoor experiment, the intention was to study the wind speed of the Malaysian road. Using well-placed anemometers along a typical route, the study sought to describe the average wind speed and whether or not it could be used to power a windcatcher. The average wind speed will be determined using the data gathered, and an interior experiment will make use of it.

4.1.1 Windspeed Reading

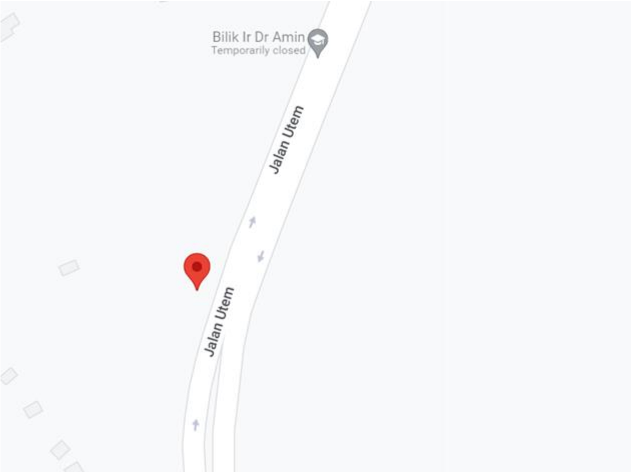

Figure 4.1: In front of UTeM main gate

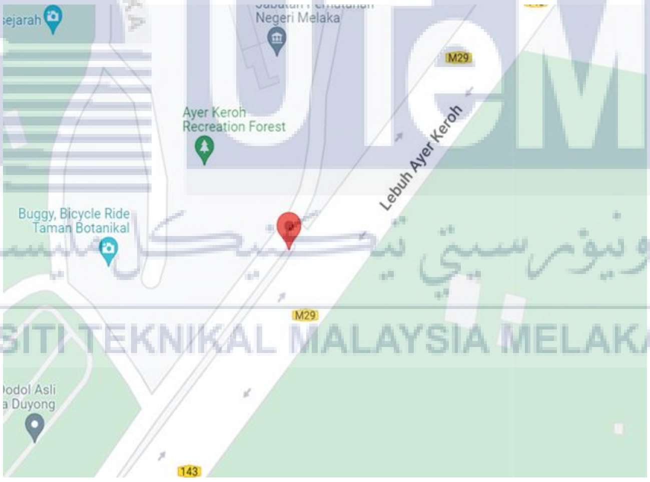

Figure 4.2: Taman Botani

By using the given anemometer, the speed of the wind from the vehicle is recorded in the 1-hour time frame. The location of the wind speed is recorded at in front of UTeM main gate (2.298537, 102.314169) shown in Figure 4.1 and Taman Botani (2.280497, 102.301086) shown in Figure 4.2.

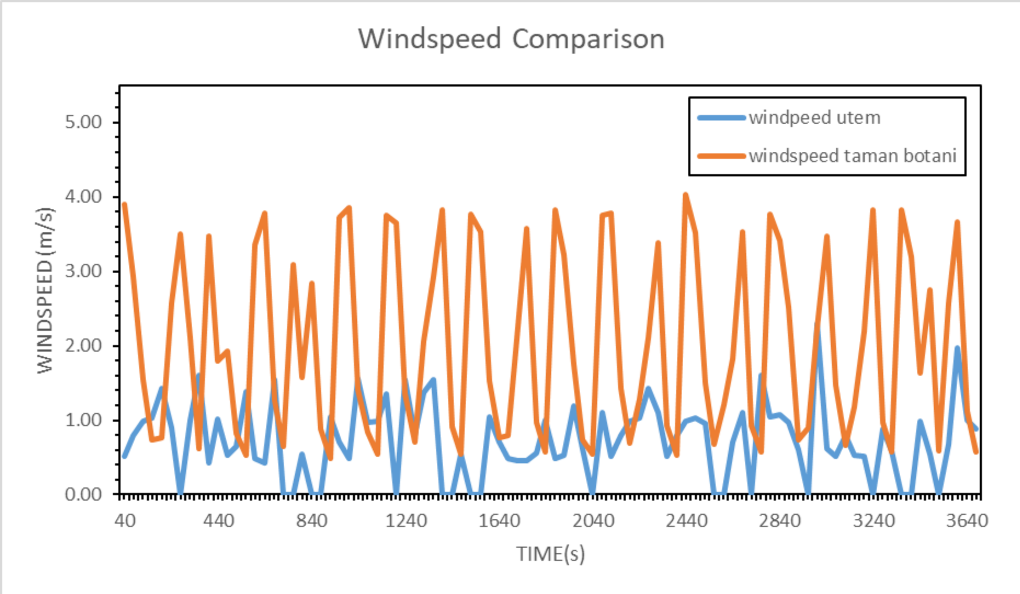

Figure 4.3: Windspeed Comparison

Table 4.1: Windspeed Comparison Table

Location	UTeM	Taman Botani
Maximum (m/s)	2.29	4.72
Minimum (m/s)	0.00	0.44
Average (m/s)	0.75	2.03

From the Table 4.1 and figure 4.3 above, the wind speed in front of UTeM main gate is slower compared to Taman Botani. This is due to the number of vehicles that pass through, as the road in front of UTeM main gate is primary used by those who need to go to UTeM compared to Taman Botani where everyone uses. This causes the road to be busier and more wind generated. The average of 2.03 m/s will be used in the indoor experiment.

4.2 Indoor Experiment

The indoor experiment intention was to study the most favorable circuit configuration so that the outdoor experiment can be done with more certainty and focus. There experiment is divided into two parts, the first part is to figure out which windcatcher structure is more suitable for the outdoor experiment while the second part is to determine the circuit what will be used for the outdoor experiment.

4.2.1 Windcatcher Circuit

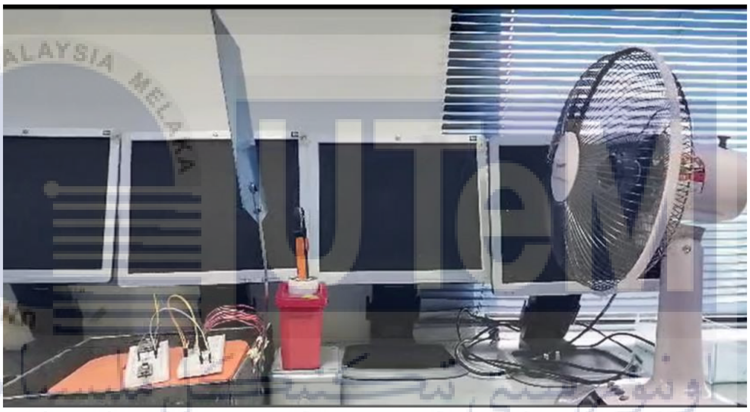

Figure 4.4: Indoor Experiment Setup

In this study, two distinct structures have emerged in the development of windcatcher. First and foremost, for both structures the same cantilever was used. The difference between structure is the piezoelectric placement and windcatcher pedals. Lastly, the same setup for both windcatcher is used as shown on Figure 4.4 above.

4.2.1.1 Parallel Configuration

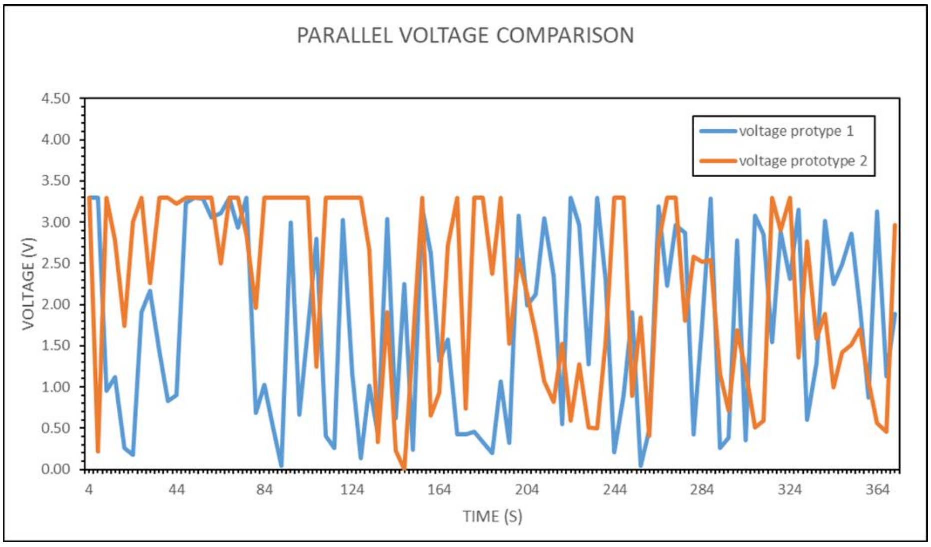

Figure 4.5: Parallel Voltage comparison

The graph shows that Prototype 2 maintains a higher voltage output for a more extended period, as evident by its curve hovering above Prototype 1's curve throughout most of the time range as shown in Figure 4.5. Additionally, the graph proves a study that a more pressure generate more energy [24].

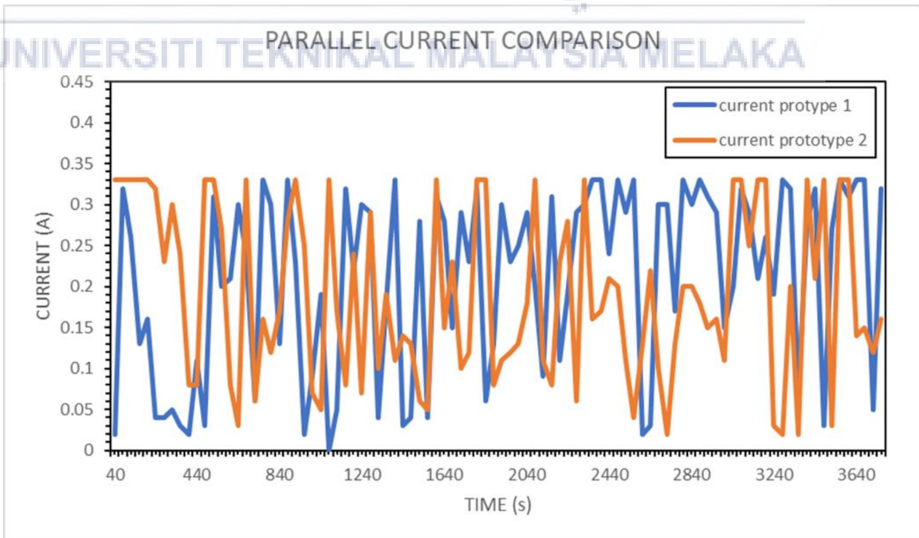

Figure 4.6: Parallel Current Comparison

The graph shows that for parallel current, prototype 1 demonstrates a more rapid decline compared to Prototype 2. However, Prototype 2 maintains a higher current output for a more extended period, as evident by its more frequent peaks as shown Figure 4.6. Moreover, the graph proves a study that a more pressure generate more energy [24].

4.2.1.2 Series Configuration

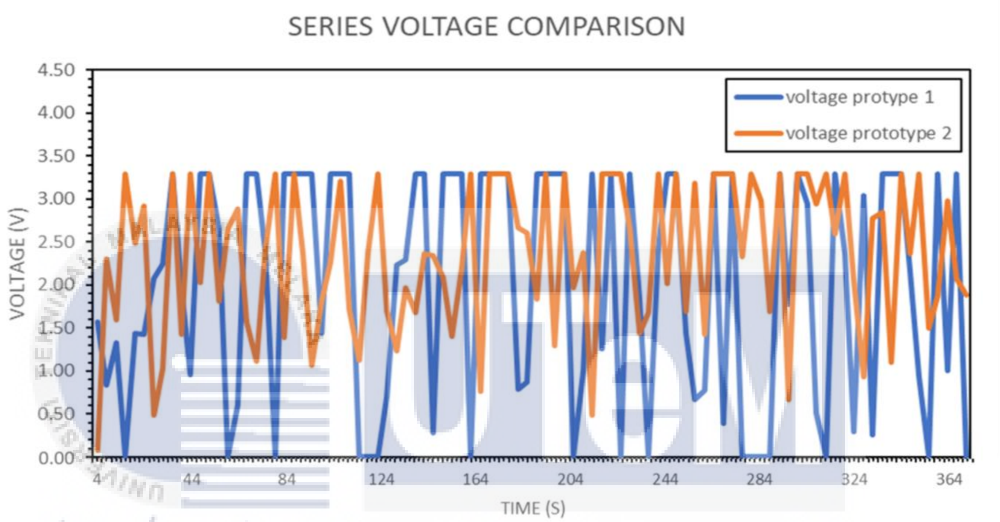

Figure 4.7: Series Voltage Comparison

The graph shows that the voltage profiles diverge, with Prototype 1 demonstrating a more rapid decline compared to Prototype 2. However, Prototype 2 maintains a higher voltage output for a more extended period, as evident by its curve hovering above Prototype 1's curve throughout most of the time range as shown in Figure 4.7. after that, the graph proves a study that a more pressure generate more energy[24].

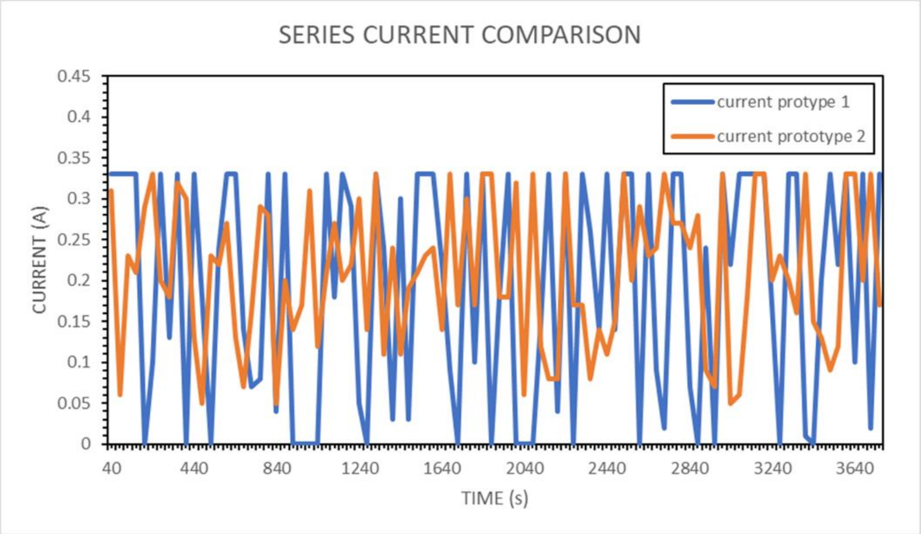

Figure 4.8: Series Current Comparison

The graph shows that the current profiles diverge, with Prototype 1 demonstrating a more rapid decline compared to Prototype 2. However, Prototype 2 maintains a higher current output for a more extended period, as evident by its curve hovering above Prototype 1's curve throughout most of the time range as shown in Figure 4.8. lastly, the graph proves a study that a more pressure generate more energy [24].

4.2.1.3 Prototype Comparison

Table 4.2: Prototype 1 and Prototype 2 Comparison

	Average Voltage (V)		Average Current (A)		Average Power (W)	
	Parallel	Series	Parallel	Series	Parallel	Series
Prototype 1	1.63	2.00	0.20	0.18	0.40	0.32
Prototype 2	2.05	2.27	0.21	0.20	0.44	0.40

As shown in Table 4.2 above, Series configuration consistently yields higher average voltage than parallel configuration, regardless of prototype. This aligns with theoretical expectations due to additive voltage in series arrangements. Prototype 2 demonstrates higher voltage output overall compared to Prototype 1, suggesting potential design or component improvements. Parallel configuration yields higher average current than series configuration, while exhibiting lower voltage. This inverse relationship is consistent with electrical principles as current divides in parallel paths while voltage accumulates in series arrangements. This output is in line with the Kirchhoff Voltage Law and Kirchhoff Current Law with parallel current are higher and series voltage are higher [25].

4.2.2 Fan Position Comparison

Table 4.3: Fan Position Comparison Table

Fan Placement	Average Voltage (V)	Average Current (A)	Average Power (W)
In Front	2.27	0.20	0.40
In Front at 45° angle	1.55	0.16	0.26
From the Side	1.70	0.17	0.29
In Back at 45° angle	1.81	0.17	0.29
In Back	1.76	0.18	0.32

A comparison of fans positioned differently in relation to the windcatcher is presented in the Table 4.3 above. Due to it producing the greatest results, the series circuit configuration was chosen. The table shows that the windcatcher's performance is significantly impacted by the fan's positioning. When the fan is positioned directly in front of the windcatcher, it produces the highest average power output and when it is positioned at a 45-degree angle, it produces the lowest. This is because the pulsating air flow produced by the oscillating fan efficiently powers the windcatcher's turbines and when the air flow is more consistent, the power output is reduced as it hinders the back-and-forth movement of the windcatcher.

Additionally, lower power outputs are produced when the fan is positioned to the side or rear of the windcatcher since the air flow is less efficient at powering the turbines in this position. However, in comparison, the back position is the second highest, this could be due to the windcatcher are designed to move back and forth, thus wind directly from the front and the back would generate greater pressure on piezoelectric element and generate better output. These findings imply that while developing or utilizing a windcatcher system, the direction of the wind source placement should be taken into account. By carefully positioning the windcatcher, it is possible to significantly increase the power output of the windcatcher [24].

4.2.3 Boost Circuit Compatibility

For this experiment 2 boost circuits were considered to be used with the windcatcher, which is Sparkfun energy harvester and Bq25570 charging circuit.

4.2.3.1 Sparkfun LTC3588 breakout board

When using the Sparkfun energy harvester, the value will rise or fall slowly based on the windcatcher swaying motion frequency. given enough swaying motion, the output value will slowly rise to 1.8V. From there, any swaying motion from the windcatcher will only fluctuate the output voltage in the range of 1.6 to 1.8V. Lastly, the Sparkfun energy harvester will only maintain output of 1.6 to 1.8V if the input is minimum 4V. Due to the standing fan oscillating speed that are not fast enough to create steady swaying motion of the windcatcher, reaching 5V using capacitor is difficult in this setting. The swaying motions themselves are influenced by wind speed and wind direction. This means that the ideal wind condition is repeated gust of wind.

4.2.3.2 Bq25570 Charging Circuit

The circuit seems to come with a built-in capacitor. When the circuit is connected to input, if the input is sufficient, the output pins and the battery pins value seem to be increasing at the same time. The output pins show value in mV while the battery pins show value in V. Even when the circuit is not connected to input, the output pins will still have reading, this may be due to the built-in capacitor. Compared to Sparkfun LTC3588, the input voltage is lower than 4V which is 0.5V. However, due to the standing fan oscillating speed that is not fast enough to create steady swaying motion of the windcatcher, reaching 5V using capacitor is difficult in this setting. The swaying motions themselves are influenced by wind speed and wind direction. This means that the ideal wind condition is repeated gust of wind.

4.2.3.3 100µ Farad Capacitor

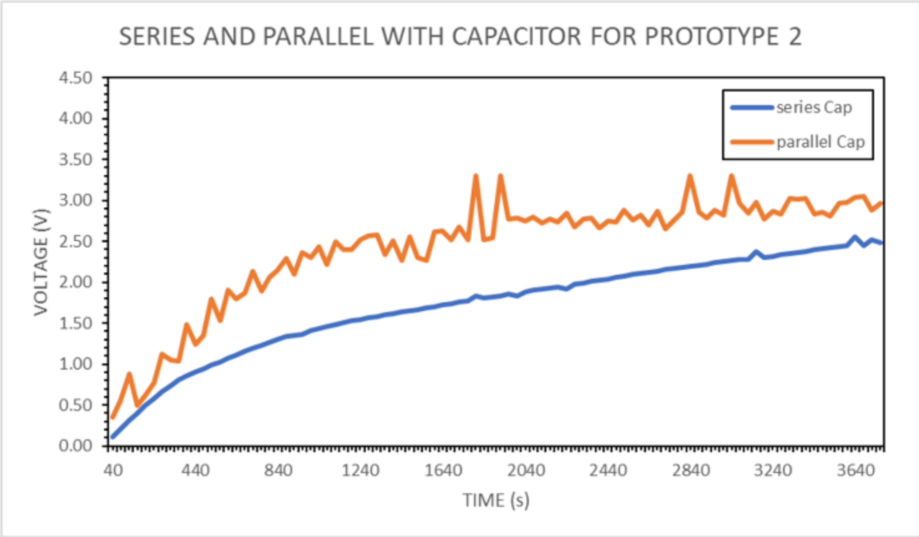

Figure 4.9: Series and Parallel with capacitor for prototype 2

Due to the failure to stabilize the output using boost circuit, a low-cost alternative for it is by connecting a capacitor across the output. Due to prototype 2 performing slightly better, the output of both parallel and series are compared as shown Figure 4.9. For the parallel configuration, it yields a higher peak voltage (around 3.3 V) compared to the series (around 2.5 V). It also showcases a steeper initial voltage rise. However, it experiences a faster voltage decay over time. As for the series configuration, it demonstrates a lower peak voltage and more gradual rise which mean that Its voltage rise is more gradual. It exhibits a slower voltage decay, maintaining a more consistent voltage output over time. This output is in line with the Kirchhoff Current Law, voltage in parallel configuration is the same, but due to the piezoelectric element being slightly different, cause the parallel configuration to be less stable than series [25].

4.3 Environment and Sustainability

For this project, in terms of sustainability and environmental friendly goals (SDG goals), two goals were reached. The first is affordable and clean energy which is SDG 7, which are reached as this project explores the feasibility of energy generated by wind and piezoelectric and can be used as a clue for better wind generator in the future. The second is sustainable cities and communities which is SDG 11, which are reached as it focuses on using the wind generated by vehicle that otherwise will be wasted. Lastly, since the project itself is proof of concept, it will provide an insight into environmentally friendly energy harvesters, and it doesn't use any volatile material. The circuit used for the data collection can be excluded.

CHAPTER 5

CONCLUSION AND FUTURE WORKS

This chapter will provide conclusion for the results acquired from the data previous chapter. This section will also provide discussion on how the project maybe improve in the future.

5.1 Conclusion

In the context of this project, an exhaustive study was carried out to evaluate the functionality of a windcatcher. This windcatcher includes a wind electric generator that makes use of piezoelectric energy harvesting technology and is designed to be deployed in strategic positions along roadways. In conclusion, the placement of piezoelectric element is important to generate maximum with respect to the mechanical stress of the cantilever material. The efficiency of the energy harvesting system was slightly improved as a result of the implementation of the piezoelectric material in series. Lastly, in terms of the output, prototype 2 performs slightly better than prototype 1.

In a nutshell, the project was a huge success, and it did an excellent job of reaching its objective. In the beginning, it required the creation of a windcatcher for the piezoelectric energy harvesting device that was made out of a single cantilever beam. Second, it required determining each windcatcher's output voltage so that comparisons could be made. In the final step of the research, an investigation into the output of the recently implemented piezoelectric energy harvesters was carried out. By achieving these goals, significant advancements were made in our understanding of the circuit layout of piezoelectric devices arranged in both series and parallel configurations. The findings indicated that the voltage generated differed greatly based on the circuit architecture. This knowledge is essential for maximizing the efficiency of such systems since it enables one to better tailor the configuration of the circuits.

5.2 Future Works

If this subject were to be explored ever further, there is the possibility that the system for energy collecting can be improved by investigating several kinds of energy sources in addition to the windcatcher. Although the integration of the windcatcher for use in outdoor experiments was the primary emphasis of this research, it is possible that the system's capabilities might be expanded by the addition of other energy sources, leading to an improvement in the system's overall efficiency. A hybrid energy harvesting system might be constructed by introducing other energy sources such as solar panels or kinetic energy harvesters into the energy collection process. This would allow for the simultaneous capture of various renewable energy sources. This would give a solution for the generation of electricity that is more resilient and reliable, particularly in regions where wind energy by itself may be intermittent or insufficient.[26]

In addition, in order to acquire a full understanding of the performance of the system, it would be beneficial to improve the piezoelectric generation using another method such as width splitting method. This would improve the windcatcher as the 2 windcatcher will move at different speeds and frequency, improving the voltage generation rate.[27] In addition, conducting these trials indoors in a controlled environment and outdoor which are more unpredictable can provide significant insights and guidelines that can be used to better understand the power generation efficiency of the system and optimize the system's performance.

It will be possible to further develop and perfect the energy harvesting system if these potential future enhancements are pursued, such as the investigation of alternative energy sources and the performance of a wide range of field tests. This would not only make it more effective all around, but it would also make it applicable in a larger variety of contexts and circumstances. In the end, these innovations may help contribute to the development of sustainable energy solutions, which would represent considerable progress towards a future that is both friendlier to the environment and more energy efficient.

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APPENDICES A: DATA COLLECTION CODING

```
#include <WiFi.h>

#include <ThingSpeak.h>


const char *ssid = "Tapiocaking";

const char *password = "t9tcjap2";

unsigned long channelID = 2135802;

const char *apiKey = "GFT8P7EE63KY8Y6W";


const float shuntResistance = 10; // Replace with your actual shunt resistor value


int adcPin1 = 34; // The ADC pin to read the value from 34

int adcPin2 = 35; // The ADC pin to read the value from 35
```

```
WiFiClient client;


// Timer variables
unsigned long lastTime = 0;
unsigned long timerDelay = 30000;


void setup() {
  Serial.begin(115200);

  WiFi.mode(WIFI_STA);


  ThingSpeak.begin(client);
}


void loop() {
```

```
if ((millis() - lastTime) > timerDelay) {

  // Connect or reconnect to WiFi
  if(WiFi.status() != WL_CONNECTED){
    Serial.print("Attempting to connect");
    while(WiFi.status() != WL_CONNECTED){
      WiFi.begin(ssid, password);
      delay(5000);
    }
    Serial.println("\nConnected.");
  }
 }

 int adcValue1 = analogRead(adcPin1);
 float voltage1 = adcValue1 * 3.3 / 4095;
```

```
float current1 = voltage1 / shuntResistance;


//int adcValue2 = analogRead(adcPin2);

//float voltage2 = adcValue2 * 3.3 / 4095;


Serial.print("ADC value 1: ");

Serial.println(adcValue1);

Serial.print("Voltage 1: ");

Serial.println(voltage1);

Serial.print("current 1: ");

Serial.println(current1);


/*Serial.print("ADC value 2: ");

Serial.println(adcValue2);

Serial.print("Voltage 2: ");
```

```
  Serial.println(voltage2);*/



  ThingSpeak.setField(1, voltage1);

  ThingSpeak.setField(2, current1);



  int status = ThingSpeak.writeFields(channelID, apiKey);

  delay(5000);

}
```