Electric Kite

By

Ibad Atif
Enrollment No. 01-133192-044

Raja Salar Haider
Enrollment No. 01-133192-113

Waleed Farooq
Enrollment No. 01-133192-138

Supervised By

Engr. M. Hasan Danish Khan

Session 2019-23

A Report is submitted to the Department of Electrical Engineering,
Bahria University, Islamabad.
In partial fulfillment of requirement for the degree of BS(EE).

Certificate

We accept the work contained in this report as a confirmation to the required standard for the partial fulfillment of the degree of BS(EE).

____________________.

Head of Department

____

Supervisor

____________________.

Internal Examiner

____

External Examiner

Dedication

This thesis is dedicated to our parents who provided us with their support and encouragement and assured us that even the most difficult tasks at hand can be accomplished if performed one step at a time. We would also like to dedicate this thesis to our supervisor Engr.M. Hasan Danish Khan for his inspiration, his cooperation and his utmost patience with us.

Acknowledgments

First and foremost, we would like to thank Allah Almighty, Who's the most Beneficent, the most Merciful, to who all praise belongs and on whom we depend for knowledge and guidance. He bestowed us with the patience and expertise required to complete our project. Secondly, our sincere appreciation goes to our supervisor Engr. M. Hasan Danish Khan for his encouragement and guidance. This project would not have been possible if it weren't for his advice and assistance. His patience helped us along every step of our project. We would also like to acknowledge the instructor for his moral and technical support and his invaluable advice on the course of our project.

Abstract

Using fossil fuels to produce electricity has various issues, such as excessive expenses, contamination, and geopolitical complications. To confront these challenges, it is advisable to opt for renewable energy sources that are inexpensive, sustainable, readily available, and eco-friendly. However, alternative energy technologies have some restrictions. According to optimistic forecasts, wind energy, photovoltaic systems and biomass could generate only a maximum of 20% of the entire energy production in the next two decades except hydropower. Currently, wind turbines are the most substantial source of renewable power; however, their construction requires massive towers and blades which can impact land use and result in noise pollution. In addition to this issue is the fact that despite increased oil and gas prices recently; investment costs for generating wind power remain high making it not competitive with thermal generators from an economic standpoint. Therefore, researchers are developing a new type of wind generator using controlled tethered kites in order to address these limitations.

Contents

List of Figures

Chapter 1

Introduction

With the global population on a continuous rise, the demand for energy is continuously increasing as well. This high demand has led to a forecasted increase of a third in worldwide energy demand by 2035 by the International Energy Agency. While wind turbines are considered the most cost-effective means of producing clean energy, there are still many areas where it is less affordable than coal-fired power plants. The challenges associated with generating electricity from fossil fuels include limited resources, high pollution and CO2 production costs, geopolitical issues surrounding producing countries, and other factors leading to high costs. To overcome these limitations and address these challenges, alternative sources of energy that are renewable, sustainable, readily available and costeffective are preferred.

However, despite its benefits and prominence in renewable energy sources (excluding hydroelectric power plants), wind turbine construction poses environmental concerns related to land usage and noise pollution while also requiring considerable long-term investments throughout its lifecycle. These factors have resulted in higher electricity generation costs compared to conventional thermal generators even with recent increases in oil and gas prices.

In response to these challenges faced by current wind power technology, scientists have developed a new class of wind turbines that aims to capture wind energy through controlled drones instead of traditional heavy towers or large blades in unfavourable terrain. Several prototypes are currently under development globally aiming at addressing energy shortages in underdeveloped regions or generating clean energy more efficiently for developed regions while overcoming common obstacles presented

Figure 1.1: Modern renewable energy generation in Pakistan, by source.

1.1 Project Background

Wind power is expected to play a pivotal role in the global pursuit of net zero carbon emissions, as it is predicted by the International Energy Association to increase tenfold by 2050. The rise in wind turbine sites and grid connections across the world has led to a significant reduction, about 40in the cost of wind energy over the past decade. Although large wind turbines are a popular choice for generating energy from wind, their high costs or logistical challenges make them impractical for some areas especially deep waters. Additionally, these turbines cannot harness the greatest wind speeds effectively. Therefore, experts propose that airborne solutions may be more effective in capturing energy from these regions.

Several companies and academic institutions have started exploring different options for airborne wind energy with varying complexities of design ranging from soft wings that rotate propellers and pull lines to more sophisticated rigid crafts that contain turbines and generators to produce electricity. These systems can reach heights up to 800 meters which surpasses even the tallest traditional wind turbines which only range between 200-300 meters tall. Additionally, studies estimate that high altitude winds can generate 4.5 times more power than ground-level winds.

The system itself is quite versatile as it can be housed inside containers making it portable and easy to relocate wherever required such as parking lots or streets where there are no solid bases for erecting large traditional turbines. It can also operate reliably in deep water conditions which would generally not be suitable for conventional turbines due to stability challenges.

The concept of using an aircraft or parafoil device tethered via a cable or cord across its midsection was proposed by an American engineer Miles Lloyd during the '70s-'80s period when he suggested two modes of harnessing energy known as Lift mode or Drag mode. When using Lift mode or tension on its tether, an aircraft follows a circular trajectory generating electricity while rolling around its axis similarly applying drag mode wherein an engine on board produces electrical power.

In conclusion, wind power through the use of airborne solutions is a promising option for renewable energy generation. With an expected increase in wind power and solar energy in the coming years, it's highly probable that these sources will fulfill up to 70% of the world's electricity needs by 2050.

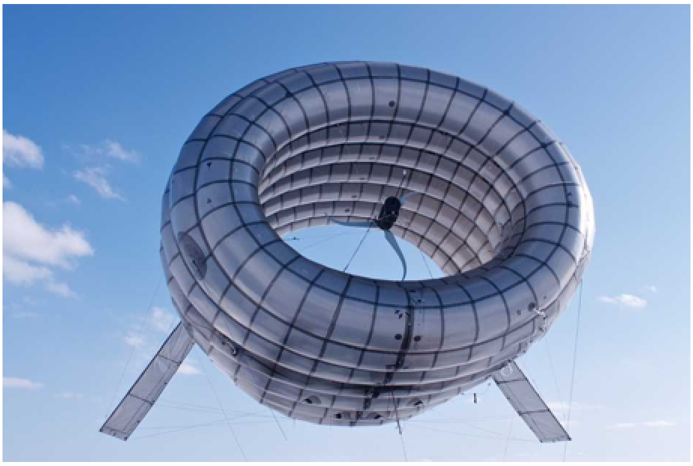


Figure 1.2: World's first Airborne Wind Turbine in Alaska

1.2 Sustainability

Airborne wind energy systems provide a promising solution for harvesting wind energy at higher altitudes, where the winds are stronger and more stable compared to ground-level winds. The wings used in AWES are tethered to the ground instead of relying on towers, which ultimately reduces investment costs and total mass. This innovative approach is perceived as cheaper and more reliable than traditional wind energy sources.

Despite these advantages, there is still an ongoing challenge in developing a reliable control system for AWES. It needs to be capable of operating even during strong wind conditions while harvesting the maximum amount of energy efficiently. Without a sophisticated control system, it would be difficult to fully utilize AWES's potential in generating renewable energy.

The success and long-term sustainability of this project heavily depend on community acceptance or rejection of the concept itself. Since airborne wind energy is still relatively new, it is important for society to adopt it widely as part of achieving sustainable development goals.

Various sustainability models exist that aim to provide guidance on achieving sustainable development objectives such as environmental, social, and economic development. Among them, the three-scope model emphasizes that sustainability requires balancing objectives across all three domains equally. By adopting this model, we can better understand how different aspects of society need to work together in order to achieve longterm sustainability that benefits everyone on both local and global scales.

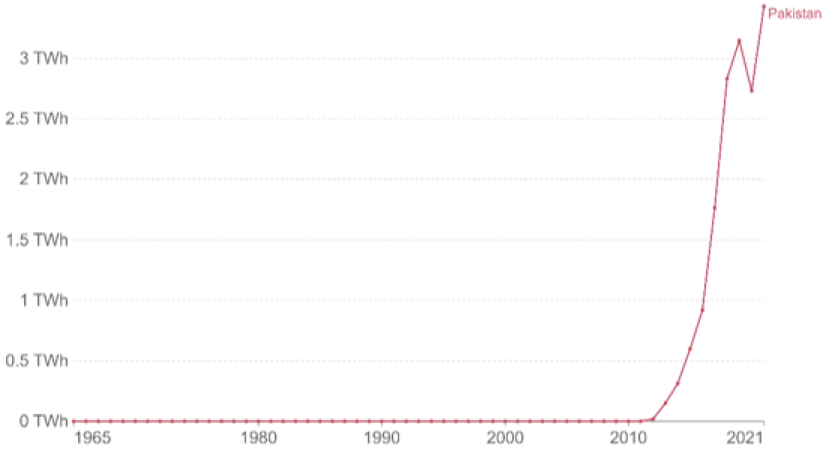


Figure 1.3: Annual electricity generation from wind in Pakistan measured in terawatt-hours (TWh) per year

1.3 Renewable Energy Sources

Reducing greenhouse gas emissions by 50-85% through 2050 is crucial to achieve the objective of limiting global warming to 2 degrees Celsius. Energy generation (heat and electricity) was found to be accountable for 38% of the total worldwide greenhouse gas emissions in a study conducted in 2013. By utilizing renewable energy sources, these emissions can be decreased by as much as 20% to 90%. The residential sector and road transport were responsible for emitting 6% and 16% of the emissions, respectively. Renewable energies such as solar thermal systems and heat pumps could provide heating and warm water in the residential area if powered by wind energy. In addition, electric vehicles and wind fuel (hydrogen or methane produced with wind power) could replace fossil fuels with renewable energy sources in the road transport sector. Therefore, renewable energy has considerable potential to reduce greenhouse gas emissions significantly.

Using renewable energy sources has benefits beyond just combating climate change. Another reason is the negative environmental and health effects caused by coal power plants. Replacing these plants with renewable energy systems could lead to improved public health and environmental conditions.

Historically, hydropower has been the leading source of renewable electricity and contributed to 15.7% of global net power generation in 2011. Biomass was the second-largest source with 3%, followed by wind at 2.8%. However, some countries have already utilized their available hydro power resources and cannot significantly increase them. This is also true for biomass. Additionally, geothermal energy can only be effectively harnessed in certain locations around the world where there is volcanic magma underground.

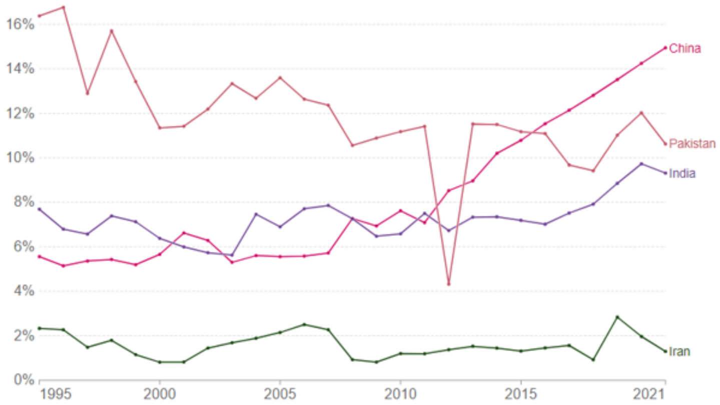


Figure 1.4: Renewable energy output over the years of Pakistan and its neighbouring countries

1.3.1 Airborne Wind Energy

Using tethered flying devices, airborne wind energy (AWE) systems can harness the stronger winds at higher altitudes to produce electricity. However, the cost of traditional wind turbines' towers increases exponentially with height, which can make taller towers economically unfeasible. Hybrid wind turbines can mitigate this issue to some extent. Nonetheless, mounting a 500-kW turbine on a 200 m tower may never be an economically viable option. In contrast, by attaching a wing to a rope, it could become feasible to operate a 500-kW system at an average height of 200 m or more using a wind power aerial device because the cost of the rope only increases linearly with height. To maintain affordability, it would be necessary to use robust cables that have long lifetimes.

Airborne wind energy devices have the potential to produce small to medium wind power by operating in the boundary layer, where wind energy is much stronger than at ground level. These devices could be beneficial for providing electricity to remote villages when combined with solar power, as relying entirely on solar energy can be expensive and requires large batteries. This combination is often a better option due to the ease of maintenance that comes with ground-level installation of the generator, which eliminates complications associated with tall towers.

1.4 Advantages over Traditional Wind-Turbines

AWEs have various advantages over traditional HAWTs. They provide commercial benefits in comparison to standard wind turbines because of their large swept wing area, generating four times more power than a HAWT blade. Moreover, AWES can fly at higher altitudes to utilize up to 20wind speeds. An integrated and mobile launch/ground platform replaces the Master HAWT for both land and sea applications, reducing construction and commissioning costs while lowering the HAWT's carbon footprint by over 50%.

An effective way to generate electricity is through aircrafts converting their kinetic energy into electrical energy with the help of a ground station. This technique is portable, inexpensive, and easy to produce, making it ideal for remote communities. The air-to-air approach utilizes lightweight composites instead of heavy traditional wind turbines, reducing their overall size by up to 90%. Additionally, this reduces the system's lifetime emissions and visible impact. Furthermore, this airborne connection allows the system to capture stronger and more consistent winds at higher altitudes, providing an advantage over ground-based turbines. Compared to conventional wind turbines in specific regions or markets, lower mass yields, simpler logistics and better power factors can result in reduced energy costs.

Chapter 2

Literature Review

AWE systems usually consist of flying objects like planes, gliders or wind turbines that are linked to the ground through tethers. The earliest research on AWE began in California, USA as far back as 1930. The firstever effort to produce energy using wind turbines was carried out in Minnesota, USA. A turbine was set up in a village and had the capacity of generating 350W electricity. In 1980, Lloyd performed an initial analysis on utilizing airplanes for generating power. He came up with a blueprint for an efficient aircraft-based power plant at a large scale.

Generating electricity of 6.7 MW is possible by employing a compound wing as big as an airplane, according to his study. The primary incentive for creating Airborne Wind Energy (AWE) systems is to harness stronger winds at higher elevations. As the elevation increases, wind speed and stability also increase while turbulence decreases. Wind turbines can achieve their maximum power output with minimal cost at altitudes above 200 meters, where wind power density triples. This has prompted the development of AWE equipment that produces wind energy at even greater heights than traditional structures allow. Even a minor increase in the height of a wind power plant can result in a significant boost in power generation.

The use of fossil fuels for power generation is a critical issue in our society. The most suitable solution to this problem is the implementation of renewable resources that are cost-effective, accessible, and sustainable for the environment. However, there are limitations to the current renewable technology available. Wind turbines are currently the predominant source of renewable energy but require massive infrastructure, including heavy towers and foundations with large blades that have a considerable environmental impact. Moreover, creating wind turbines requires significant investments and has long-term payback periods. This leads to the non-competitive economic viability of fossil fuel despite increasing gas and oil prices. Additionally, wind farms face challenges regarding land occupation and environmental impact due to electricity production density being significantly lower than thermal power plants.

2.1 Thesis Objective

This thesis endeavors to present a systematic and well-planned methodology for designing ground control units and voltage management systems that are optimized for kite powered systems. The primary objective of this research is the safe and efficient construction as well as operation of kite power systems. It is important to note that various environmental factors such as wind speed, profile, and turbulence intensity can significantly impact the effectiveness of a kite power system. Therefore, this study will conduct an in-depth analysis to examine the impact of these variables on kite power systems. By doing so, this research aims to provide valuable insights into the optimal design and operation of kite-powered systems to maximize their efficiency while maintaining safety standards

2.2 Methodology

In order to successfully design and develop kite-power systems, this project takes on an interdisciplinary approach, drawing from the knowledge and expertise of multiple fields such as aerodynamics, material science, electrical engineering, and general engineering. Through this collaborative effort, the team can gain a broader perspective on the challenges associated with designing these systems and work towards finding practical solutions that are both energy-efficient and cost-effective. The end goal of this project is to produce large quantities of kite-power models that can be deployed in regions where traditional energy options are limited. By doing so, the team hopes to contribute towards sustainable development and increase access to affordable sources of energy while minimizing environmental impact.

Studies conducted earlier have primarily concentrated on increasing the power output during the unwinding stage of a pumping kite power system. Nonetheless, it is equally essential to lay equal emphasis on the winding phase that employs the electric energy produced during the unwinding phase. For optimal performance throughout the entire cycle of phases, it is crucial to establish a swift dynamic model capable of recognizing flight paths that are most effective. In other words, both stages of a pumping kite power system are critical for its efficient functioning, and therefore they deserve equivalent consideration while conducting any research or development in this domain. A rapid dynamic model can enable us to identify ideal flight paths that conserve and effectively utilize energy generated during both winding and unwinding phases of this innovative power generation technology.

The field trials have been designed to test the adaptability of several key components of the kite flying system, including its flexible airframe, voltage management system and decentralized control system. The ultimate goal of these trials is to confirm that the necessary hardware for controlling tethered kites during flight is in place and functioning correctly. By putting these components through rigorous testing in real-world conditions, researchers can gather data on their performance and identify areas where improvements may be needed. This information can then be used to refine the design of future kite flying systems, ensuring that they are both safe and reliable when deployed in a range of different scenarios.

2.3 Kite Powered Systems

Airborne Wind Energy Systems (AWES) are machines that convert the energy of the wind's motion into electrical energy using electro-mechanical means. These systems typically involve a ground station and an aircraft, which are connected by ropes or tethers and linked mechanically and electrically. Among all the AWES concepts, there are two kinds: Ground-Gen systems, which convert mechanical energy into electrical energy on the ground, and Fly-Gen systems, which do this conversion in-flight.

This thesis is dedicated to studying a specific type of airborne wind energy system that utilizes a tethered parafoil kite to generate electricity from wind power. The main components of this single-tether kite power system include the parafoil kite, which is supported by a bridle system; the tether; and the drum-generator module, located at the ground station.

The control unit for the kite is situated on an arm of a vertical axis rotor that connects to an electric drive capable of working as both generator and motor. During traction phases when there's enough wind to pull the rotor arm with sufficient force, control programs ensure maximum generated energy output from having the kite pull on it. When it becomes impossible to generate any more power during these phases, controls shift to drag mode instead. At this point,the kite gets steered towards regions where dragging actions require only negligible fractions of what was generated earlier during traction mode.

This process then continues until such time where new traction phases begin again for further generation cycles

2.3.1 Working Principle of Kite Powered Systems

The system that harnesses power from the pumping kite operates by following a set cycle. Initially, the kite is flown in a crosswind pattern to harvest traction power which is then converted into electrical energy through a generator attached to the drum. Next, it is depowered and brought back in with low force, which requires some energy that was gained during the reel-out phase. An illustration of one such power cycle starting at a thick red dot is given below. The kite first flies towards an intermediate point on the side of the wind window and then gains altitude as the tether is reeled out while flying. The maximum tether length nearly reached, prompts the kite to steer upwards after which has its set force reduced resulting in depowering; now begins the reel-in phase where it returns to its initial position. This marks the beginning of another cycle.

In this mode of extracting airborne wind energy using tethered wings, periodic pumping cycles are employed by flying high-lift orbits around wind vectors that produce high tension leading to payout from a tether drum providing mechanical power on ground stations driving shafts. At maximum tether length, power generation ends and recovery starts which entails flying wing at low lift configuration and winching it back into starting tether lengths using only part of previously generated power for this purpose.

At ground stations, electrical takeoff results from connecting generators via drivetrains to tether drums ensuring optimal utilization of harvested energy for desired outcomes.

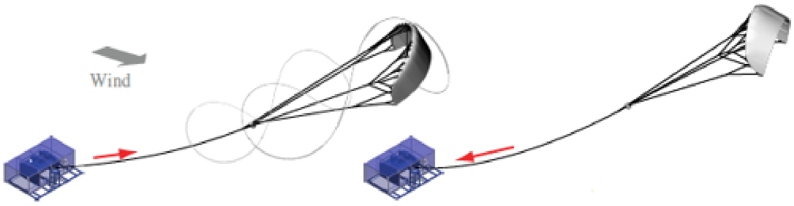


Figure 2.1: One the left sided figure the kite is in reel out phase, in which energy is generated. Whereas, on the right sided figure the kite is in reel in phase in which energy is consumed.

2.3.2 Types of Kite Powered Systems

When it comes to kite power systems for pumping operations, there are a variety of methods available. Among these approaches are the use of different types of kites, such as soft, semi-rigid, or rigid wings, and the utilization of one or more tethers to control the kite's movement. Soft kites can be either leading-edge inflatable or ram-air based on their structural elements. Leading-edge inflatable soft kites typically have tubes that provide support to the structure while ram-air kites do not require any additional support mechanisms. By using just one tether instead of multiple ones, tether drag is minimized and launching and retrieving become simpler procedures. Three-line systems boast ground-based motors and electronics which contribute to enhancing system reliability. While two-line systems essentially depend upon steering from the ground in conjunction with an actuator in the air to alter the angle of attack - acting as a middle ground between one-line and three-line approaches.

The rule that we strictly followed is rooted in the ground-gen kites, which operate using tethers and soar through the air with the aid of a parafoil kite. This principle has been tried and tested, and has proven to be highly efficient for its intended purpose. As for the different parts that make up this magnificent device, they are enumerated as follows:

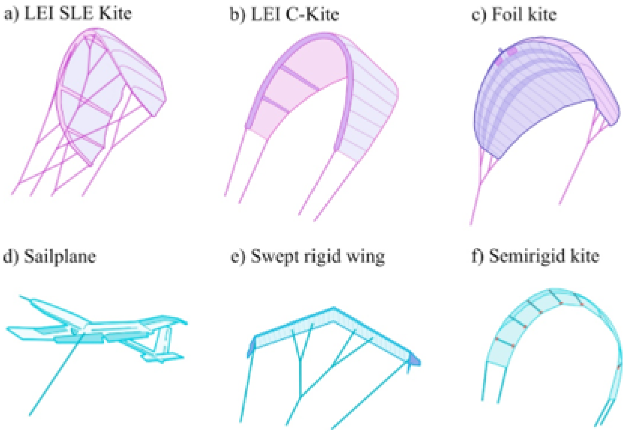


Figure 2.2: Different configurations of AWEs

Crosswind kite power refers to an innovative method of harnessing wind energy that involves a specific type of airborne conversion system. This revolutionary technique uses a kite with energy-harvesting components that can fly in crosswind mode, specifically either the whole wing set or simply the tether set. This form of wind energy technology does not require any towers and can be used as both high and low altitude devices, with its range varying from small toy-scale models to large power-grid-feeding systems. One major advantage that this unique mechanism has over traditional wind turbines is its ability to collect wind power from an area multiple times greater than the wing's own area, while flying at high speeds in crosswind mode.

Furthermore, compared to standard wind turbines, crosswind kite power systems have many benefits, such as providing access to stronger and more consistent wind resources, a high-capacity factor and the flexibility to be used both onshore and offshore at comparable costs without requiring a tower. Additionally, it's interesting how the aerodynamic efficiency of these kites can vary greatly depending on their design. The movement of tethered wings in this system is often similar to that found on the outer reaches of conventional turbine blades. However, unlike typical turbines which utilize spinning blades set up against the direction of the wind flow for energy production; crosswind kite power systems take advantage of spinning blade sets placed in a kite-power system which cut through crosswinds opposing its direction for maximum energy output

2.3.3 Parafoil Kite

The parafoil kite, a popular type of kite, is designed with cutting-edge composite materials and inflated with air. Its unique shape is defined by the size of its fabric panels and anchor line system. The parafoil consists of two airfoils, one on top and one on the bottom. These airfoils are made up of numerous fabric elements that are divided into individual cells by ribs. These partitions help maintain the airfoil geometry under tension, ensuring maximum aerodynamic efficiency when in flight. In order to increase its power and lift capacity, cells can be cut into the parafoil at specific points. To keep its perfect shape while in flight, the parafoil compresses air through vents located near the front edge of the foil. Precise control over this leadingedge compression is achieved by adjusting a brake line attached to small rudders present on both sides trailing edge of the foil. By deflection of an asymmetric brake line release mechanism that controls rocker and roll joint steering operations can be performed effortlessly.

The flow pressure across wingspan is maintained by slats forming part of an efficient airframe system for distributing aerodynamic force evenly throughout the structure. Lashing lines attached to the underside maintain wing loading and geometry thereby providing excellent stability in high winds or turbulent conditions.

In summary, this kite's complex design allows it to achieve exceptional control during flight while also generating enough lift to make it suitable for a wide range of activities such as skydiving or paragliding. Finally, the formula used to calculate stagnation pressure (when fluid velocity is zero) equalling total pressure (sums all types) gives us an insight into how intricate fluid dynamics plays a crucial role in designing such kites effectively! The mathematical equation provided is used to calculate the total pressure (Po) in a fluid system. The equation consists of three variables - Va, ρ, and Ps. Va represents the velocity of the fluid, while ρ represents its density. Ps refers to any additional pressure present in the system. The equation shows that Po is directly proportional to the square of Va, multiplied by half of ρ. This means that as either Va or ρ increases, so too will Po. In addition to this, there is a constant term (Ps) added to the final calculation which accounts for any external factors affecting the system's overall pressure. By utilizing this equation, engineers and scientists can gain insight into how different components of a fluid system contribute to its overall pressure and make informed decisions about how best to optimize it for efficiency and safety purposes.

In order to reduce the overall weight of the aircraft and improve its aerodynamic performance, ultra-high strength-to-weight ratio polymers are utilized in both the struts and main connectors. These specially designed materials are able to provide an exceptionally high amount of strength while weighing significantly less than traditional metals that have been used in such components in the past. This results in a lighter aircraft that is more fuel-efficient and capable of reaching higher speeds with greater ease. By incorporating these advanced polymers into the design, engineers are able to optimize the aircraft's performance and make it more competitive in a constantly evolving industry

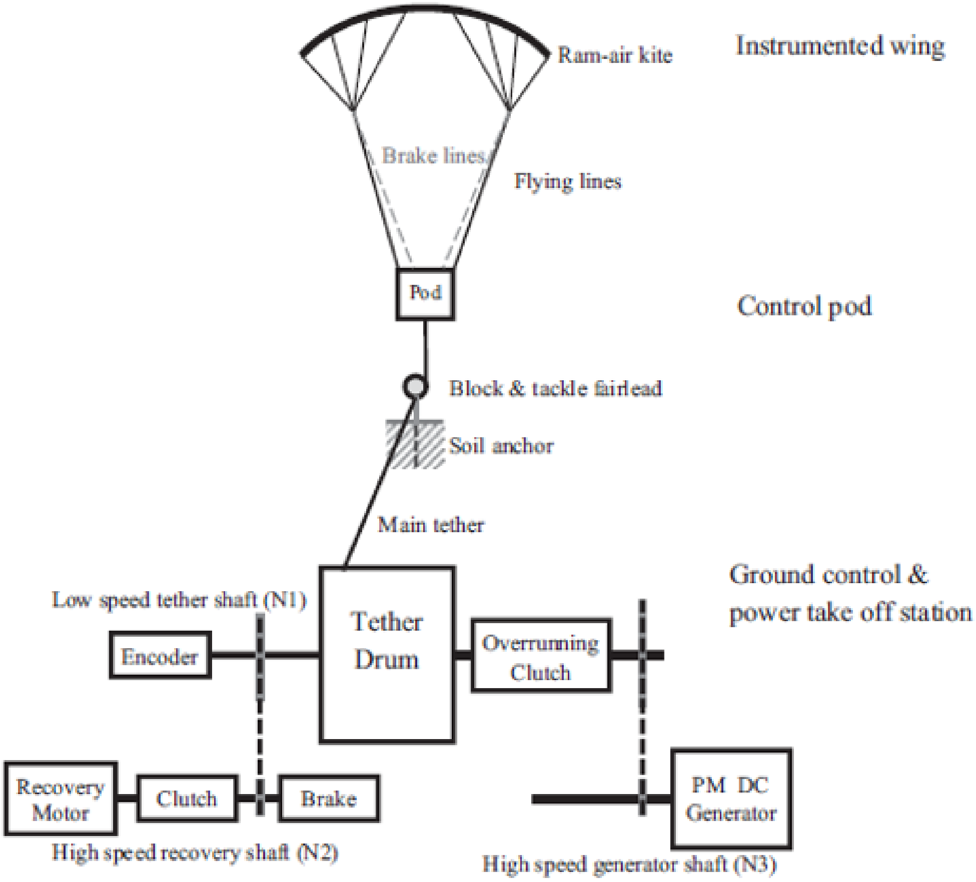


Figure 2.3: Control system arrangement

2.3.4 Tether

The tether that is used in electric kites plays a crucial role as it serves to connect the kite with the ground station. To ensure optimal performance and longevity, the tether must be made of metal composite wires encased in a strong covering. The length of the tether is an important factor to consider as it directly affects both the kite's rotation speed and drag, as well as the overall durability of the tether. It is recommended to use a high-strength composite fibre wrapped around an aluminium wire when creating the perfect tether for an electric kite.

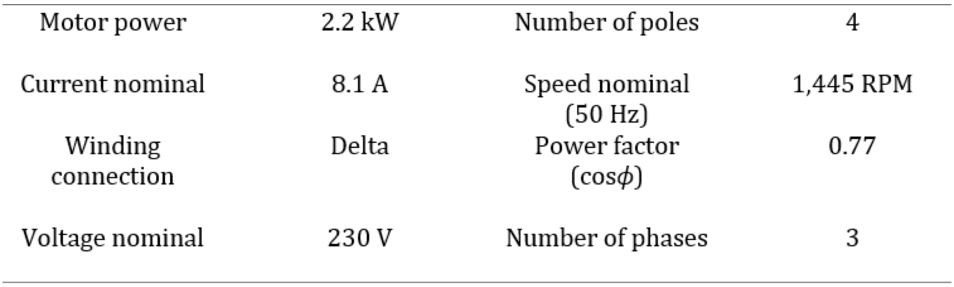
When it comes to airborne wind energy (AWE) systems, there are additional considerations that must be considered. In this case, the ideal tether must be thin yet incredibly strong and sturdy. Its lightweight nature will minimize aerodynamic drag while maximizing both operational efficiency and energy output. Additionally, since this type of system requires constant winding and unwinding around a generator's pulley - up to one million times per year - it is essential that its durability is top-notch.

In conclusion, creating a reliable and efficient tether for electric kites and AWE systems requires careful consideration of various factors. These include aspects such as material composition, length, strength-to-weight ratios, durability against wear-and-tear over time due to repeated winding/unwinding cycles around generators' pulleys in harsh environments - all critical concerns that should not be overlooked in any design or implementation process involving these cutting-edge technologies.

2.3.5 Ground Control Station

The Energy Kite, an innovative airborne wind energy technology, has a unique resting place when it's not soaring high in the sky. The ground station serves as a base for the kite and holds the tether that connects it to the generator on the ground. This is quite different from traditional wind turbines whose footprint on land can be massive. The compact design of the ground station ensures that only a small area of land is required to house it.

Moreover, one of the essential features of the ground station is its ability to determine how far out into the sky the kite can fly by controlling the length of its tether. Additionally, all critical components of this groundbreaking electric kite are located in this central hub- generator, clutch, tether drum, and recovery motor - while all operational controls are housed within a main control box also situated at this location. This centralized location allows for easy access and control over maintenance and operations while minimizing unnecessary movement around multiple locations.



Motor power	2.2 kW	Number of poles	4
Current nominal	8.1 A	Speed nominal (50 Hz)	1,445 RPM
Winding connection	Delta	Power factor ($\cos\phi$)	0.77
Voltage nominal	230 V	Number of phases	3

Figure 2.4: Induction motor specifications.

2.3.6 Ground Winch Station

The electric kite assembly is a complex and sophisticated system that relies heavily on its main station. This central hub is responsible for controlling the movement, speed, and power generation of the entire system. To achieve this, servo drives are used to regulate the length and speed of the connector and adjust the mechanical current. It's important that the fastener is securely placed into the hook through the fairing, ensuring proper alignment with the top of the drum. The clutch drum plays a critical role in providing leverage and holding tension on the overdrive clutch while transforming it into mechanical torque on the driveshaft.

The prototype drivetrain consists of three drive shafts: a low-speed main shaft with a connecting drum, a high-speed recovery and braking shaft, and a high-speed power shaft. An encoder is installed on the low-speed shaft to measure length and speed accurately. It provides closed loop position control during recovery phase monitoring.

The safety of personnel operating this electrical system is fundamental; therefore, electrical safety devices have been incorporated throughout its design to ensure safe operation at all times. In addition, there is also an emergency stop button conveniently located on front panel that will quickly halt all operations when activated. When triggered it applies electromechanical brakes instantly to bring everything to an immediate standstill. When it comes to power generation within this system, regenerative recovery function has been employed by using a three-phase induction motor connected directly to variable frequency drive for optimum efficiency. Mechanical power generated from here gets delivered through drivetrain which allows take-off of electrical power by using dedicated permanent magnet DC generator. Furthermore, a dump load generator has also been included which provides added functionality as it acts as a circuit sink for any excess electricity produced by switching parallel dump resistors thereby increasing electrical load capacity The mechanical power is delivered through the

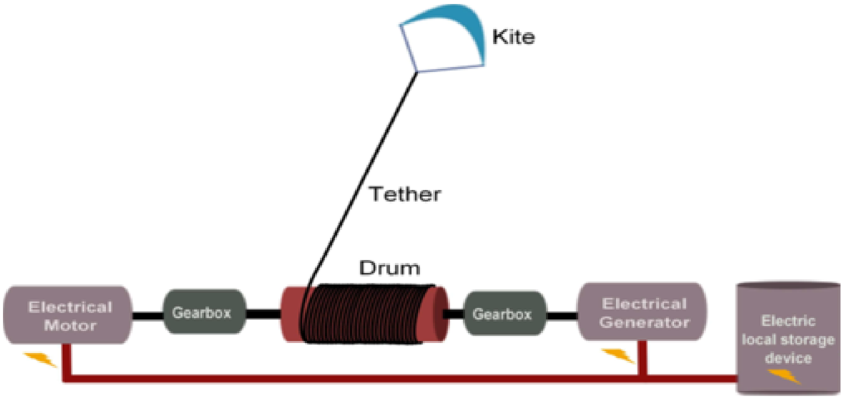
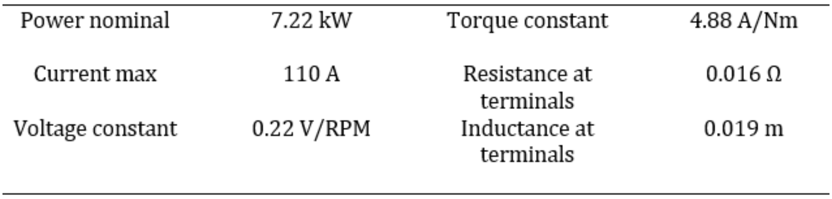


Figure 2.5: Ground station using two separate electrical actuators and a storage device

drivetrain for electrical power take-off by a dedicated permanent magnet DC generator. The generator dump load provides a power sink circuit for the generator. The dump resistors are switched parallel such that when an



Power nominal	7.22 kW	Torque constant	4.88 A/Nm
Current max	110 A	Resistance at terminals	0.016 Ω
Voltage constant	0.22 V/RPM	Inductance at terminals	0.019 m

Figure 2.6: Permanent magnet DC generator specifications.

additional resistor is activated, it is switched in parallel with the existing load, which increases the electrical load.

2.4 Estimation and Control Algorithms

2.4.1 Definition of Axes and Coordinates System

In order to determine the direction and position of the aerial system, a Cartesian coordinate system that is right-handed is used. For this purpose, the parafoil is treated as being rigid and has six degrees of freedom. The three axes, Xp, Yp, and Zp have their origin located close to the aerodynamic center of the parafoil. The positive x-axis is towards the leading edge, while the y-axis lies outside of the wing star, and finally, down in the symmetry plane of the wing is where we find z-axis with its positive value. This information can be visualized in a picture illustration. To plot Euler angles for roll, pitch, and yaw clockwise along x-, y-, and z-axes respectively follows aviation industry's general convention.

The Earth axis (XE,YE,ZE) has its origin set at the anchor position of device where all fairleads and guides exit from it. With X-axis pointing magnetic north; Y-axis pointing eastwards; subsequently Z axis normal to Earth's spheroid make up a fixed axis.

The wind axis system is determined by rotating ZE axis towards wind direction ψw with XE being parallel to wind vector Vw. It's worth noting that despite potential expenses and logistical difficulties experienced in remote or deep-water locations; parasails still offer benefits because they grant access to high wind speeds which are otherwise hard-to-reach via other means.

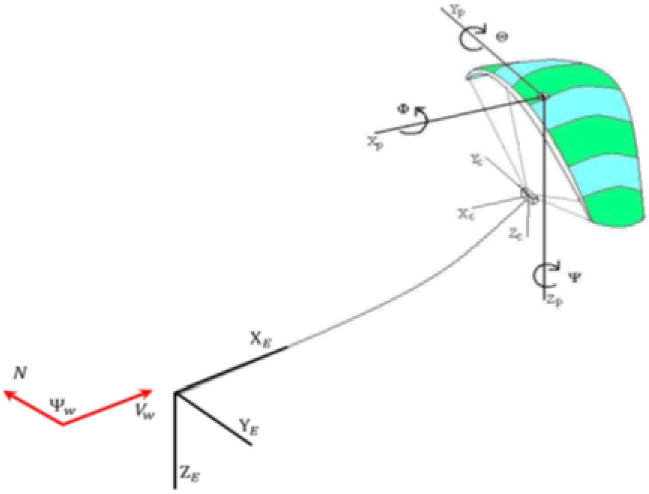


Figure 2.7: Coordinate System definition

2.4.2 Wind Profile Estimation

In order to determine wind speed at a particular height, a wind velocity log law is commonly utilized. This method involves the use of a reference wind speed (V(w,href)) measured at a certain reference height (href), which serves as the basis for calculating the wind speed at any other altitude. The formula used for this calculation takes into account surface roughness length, z0, which varies depending on local terrain features and obstructions within the area.

Archer (2013) elaborates on this methodology by assigning different values for z0 based on various types of farmland. For open farmland with widely spaced wind breaks that are more than 1 km apart, z0 is set to 0.1 m. However, farmland with numerous windbreaks is assigned a value of 0.4 m, since these obstructions drastically impact air flow patterns. In areas where there are few windbreaks but not enough to qualify as open farmland, an intermediate roughness length of 0.2 m is employed.

It's important to note that Archer's recommendations may not be universally applicable and should be adapted based on local environmental conditions and topography. Nonetheless, understanding how surface roughness affects wind velocity calculations can provide valuable insights for predicting energy generation from turbines or modeling dispersion of airborne pollutants in urban or rural areas alike.

2.4.3 Downwind and Crosswind Position Estimation

In order to accurately measure wind speeds and generate useful data, the wind station is strategically designed to face against the direction of the wind. This is achieved by utilizing an earth anchor as the starting point for the wind axis. The positioning of these anchors is crucial in determining plane descents and intersections, which ultimately dictate how the station functions. To achieve precise anchor positions, GPS technology is implemented to guide the placement of mooring anchors. In order to calculate distance between two sets of coordinates (lat1, lon1) and (lat2, lon2), a formula known as the Haversine method (Sinnott, 1984) is utilized. This mathematical equation involves numerous steps such as computing differences in longitude and latitude and ultimately arriving at a value for distance between two points based on interval value d. However, before applying these formulas it's important that longitude and latitude values are converted into radians first so that calculations can be conducted accurately.

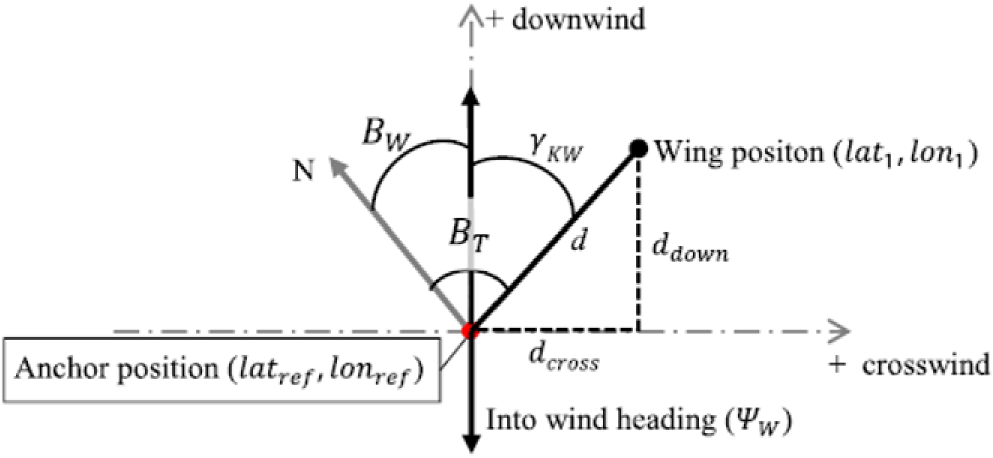


Figure 2.8: Kite to wing angle positions

2.4.4 Azimuth and Elevation from Cartesian Position Estimates

Kite pilots rely on various factors to determine the position of their aircraft. These include the altitude estimate, crosswind and downwind distances, azimuth and elevation angles between the wing and anchor point. The wind window is a common spherical coordinate system used by kite pilots to refer to the aircraft's position. It forms boundaries within which the windpowered wing can fly and includes left and right boundaries. The pitch angle and low azimuth are key factors that contribute to increasing crosssectional lift of the wing, thereby creating a high density and mechanical strength in an area known as the wind window force band. The wind window force band is responsible for providing stability to the kite during flight, making it an essential aspect for kite pilots to consider when determining aircraft position. Additionally, understanding how changes in pitch angle or azimuth can affect lift can also help pilots make necessary adjustments during flight in order to maintain optimal performance.

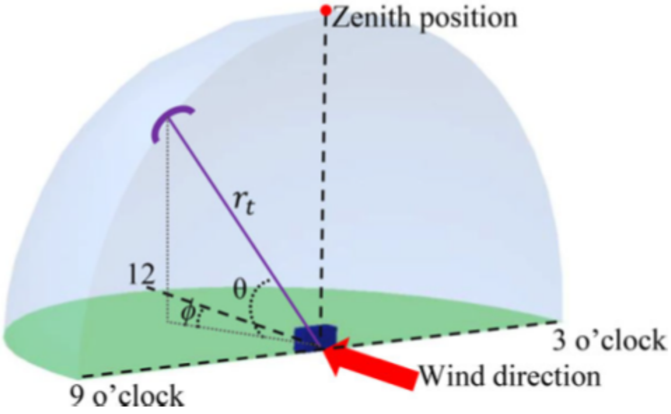


Figure 2.9: Kite angles.

Kite pilots have a unique way of describing the position of their aircraft, which is based on a spherical coordinate system called the ”wind window.” This system is illustrated in the accompanying figure and consists of two boundaries, one on the left and one on the right, that define where the compound wing can fly using wind power. By adjusting both pitch angle and low azimuth, kite pilots can increase the cross-sectional lift of their wing to create higher density and mechanical strength in a particular region known as the ”wind window force band.” This area allows for greater control over flight movements while maintaining stability within this specific range. Kite pilots rely heavily on their understanding of this wind window force band to maneuver their kites effectively during different weather conditions for recreational or competitive purposes.

Chapter 3

Requirement Specifications

The challenge of generating power from finite, non-renewable resources is a major issue that needs to be addressed by society. One possible solution is to shift our focus towards renewable energy sources that are environmentally friendly, readily available and cost-effective. However, while renewable technology offers promising benefits, it has its limitations. Although wind turbines are currently the leading source of renewable energy generation, their construction requires substantial investment and long amortization periods due to heavy towers, foundations and large blades that have a significant environmental impact.

Moreover, wind farms pose challenges of land occupation and low electricity production in covered areas compared to thermal facilities. Given these limitations of traditional wind turbines, innovative airborne solutions like Airborne Wind Energy Systems (AWES) can provide an alternative means of capturing high-altitude winds using a wide range of technologies from soft wings propelling propellers and pulling aircraft lines to complex rigid craft carrying useful energy with turbines and generators connecting electricity.

With AWES reaching heights up to 800 meters - nearly 4.5 times more than what's collected at ground level - they offer unparalleled potential for power generation without relying on fossil fuels or conventional wind turbines' drawbacks. These systems are portable as well as easily anchored in deep water where traditional wind turbines cannot reach; this adaptability allows them to be deployed virtually anywhere with strong winds even in remote areas or deep-sea environments.

It's worth noting the height-adjustability feature helps maximize output as the system can be moved up or down according to seasonality patterns when winds change strength depending on the time of year. This technology represents a key innovation for renewable energy production since it is inexpensive while being environmentally sustainable compared with traditional power generation systems that rely on finite resources such as oil or gas whose prices continue rising despite concerns about climate change issues associated with their use.

3.1 Existing Systems

Wind turbines operate on a relatively simple principle, where the kinetic energy from the wind is harnessed to produce electricity instead of utilizing electricity to create wind. The blades of the turbine are propelled by the force of the wind, leading to its rotation around a rotor, which then produces electrical energy through a generator. This generated electricity can be used in various applications such as powering homes or businesses. Vertical axis wind turbines have an overall design that comprises lengthy blades connected to a tall tower that ranges between 200 and 300 meters high. As air passes through these blades, they turn and generate mechanical energy that is then converted into electrical power via generators. This produced electricity can either be stored or transmitted onto an electrical grid for later use.

However, despite this technology's effectiveness so far, there is still significant room for improvement in increasing efficiency and generating more significant amounts of renewable power from vertical axis wind turbines. There exists ample opportunity for innovation to develop new technologies capable of more comprehensive harnessing of wind power's potential

3.2 Proposed Systems

The field of Airborne Wind Energy Systems (AWES) includes a group of mechanical devices that capture the kinetic energy of wind to produce electricity. AWES systems are comprised of at least one aircraft, which is tethered to a ground station, and in some cases multiple aircrafts. This thesis focuses on the development of a specific type of AWES known as Fly-Gen, which converts mechanical energy into electrical energy both on the ground and in the air.

To further explain, the kite control unit is an integral part of the Fly-Gen system and is situated on the arm of a vertical axis rotor. The mechanism is attached to an electric motor, which serves as a generator when the kite pulls on the rotor and as a thruster when it pulls against the wind. When in thrust phase, this control mechanism ensures that maximum power is generated by pulling on the rotor arms using kite force. In situations where no power can be produced, such as during drag phase, only a small fraction of energy expended to pull up kite rotor will be used while generating ample power during subsequent thrust phase.

The primary goal behind developing airborne wind energy systems centers around accessing stronger winds at higher altitudes where wind speeds are greater and more consistent while turbulence decreases significantly. Wind turbines placed above 200 meters have proven to be more efficient than those installed closer to ground level while also being less expensive due to producing more energy per turbine at higher elevations where wind power density is greater. As such, AWES has gained popularity for its ability to generate renewable energy from high altitude winds through innovative methods that surpass traditional wind turbines; even slight elevation increases for these plants result in amplified electrical outputs..

3.3 System Requirements

3.3.1 System Modelling

Airborne wind energy systems (AWES) are complex structures composed of various subsystems that fall under three distinct categories namely, aerodynamic, structural, and electrical components. The kite's aerodynamic model is included in the aerodynamic subsystem while the motors, axles, and drive train models make up the structural subsystem. Meanwhile, generators, inverters, and system control modules complete the electrical subsystem. All these different parts must operate together smoothly to capture high-altitude wind energy safely and effectively. The design and optimization of each individual subsystem are essential for AWES to succeed as a whole. There is also room for growth in materials science which can lead to more advanced AWES structures with greater efficiency and affordability. Additionally, improvements in control systems and software have made it possible to build smarter AWES technology that maximizes wind energy production

- **Aerodynamic Modelling**

  Airborne wind energy is the process of capturing high-altitude winds through the use of tethered devices that function as airborne wind turbines. This system works by utilizing principles of aerodynamics, which helps predict local flow conditions and calculate the aerodynamic force acting on each element of the kite in relation to its part. By doing so, we can understand how lift and drag forces work, where lift pulls upwards perpendicular to the incoming flow while drag pulls parallel to it. Essentially, understanding these principles is crucial in designing an efficient and effective airborne wind energy system as changes in current conditions produce instantaneous changes in the aerodynamic force generated.

As someone who specializes in this field, I cannot stress enough how critical it is to have a comprehensive grasp of these intricate systems. Aerodynamics plays a fundamental role not just in design but also optimization of airborne wind energy technologies for maximum efficiency when converting kinetic energy from high-altitude winds into renewable electricity.

- **Structural Modelling**

  When designing an Airborne Wind Energy System (AWES), the most critical aspect to consider is its structural model. A successful AWES requires a combination of both rigid and flexible bodies in the model depending on the dynamics it needs to capture accurately. For instance, during investigations into AWES's structural dynamics, elements such as the tether, kite, and drive train are modeled flexibly while others with more straightforward electrical dynamics can be separated by solid masses.

  It is notable that modeling tether and kite dynamics can prove difficult owing to their nonlinear nature. Thus, for safe and efficient operation under various wind conditions, sophisticated modeling techniques and simulation tools are necessary. The design and optimization process of an AWES must take into account these unique features.

  Furthermore, specific operating conditions affect the selection of an appropriate structural model for an AWES. For example, offshore AWES used for generating wind energy may require a different modeling approach from those used for onshore applications because of varying factors such as wind conditions, wave loading parameters and platform design needs. In summary, the success of an Airborne Wind Energy System is heavily reliant on appropriate structural modeling that takes into account all unique operating conditions.

a.Kite

For cost simplicity, flexible body motion is considered as a superposition of the first eigenmode. This is proven by the fact that high values are detected in real measurements and the presence of negligible energy content.

b.Drive Train

The drive train is an indispensable component of any airborne wind energy system as it is responsible for efficient power generation. It performs this function by allowing high torque at low speeds and low torque at high speeds. The two-mass model of the drive train considers both the rotor's and generator's inertia and divides them by the spring stiffness and damping coefficient. On the other hand, in the one-mass model, a single mass represents the combined inertia of both rotor and generator. It's important to note that choosing between these models depends on various factors such as wind turbine size, design, and intended use of the system.

In order to maximize energy output while minimizing complexity and maintenance requirements, it becomes essential to choose a model that fits all necessary criteria effectively. Factors such as material selection, construction cost, environmental impact including noise pollution are also crucial determinants in making this choice.

Considering all these factors before choosing a particular drive train will ensure that an effective airborne wind energy system can be designed with optimum efficiency. Ultimately, efficient power generation through proper drive train selection holds great potential towards meeting our future energy demands sustainably

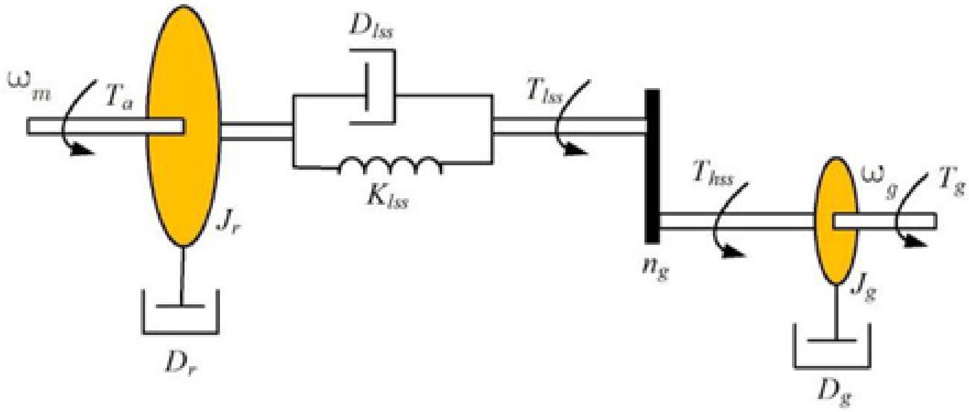


Figure 3.1: Two mass model of drive-train

- **Generator Modelling**

  Having conducted an extensive analysis of multiple generator options, we have finally concluded that the squirrel cage induction generator is the most optimal choice for us. This decision has been based on several advantages that this type of generator offers over other available alternatives. Firstly, it is highly economical and falls within our budget constraints, thereby making it a financially feasible option for us. Secondly, its design is uncomplicated and straightforward, which means that it is easy to operate and maintain without requiring any specialized technical knowledge or skills.

  Moreover, another significant advantage of selecting this type of generator is that it can be readily replaced in case of any malfunction or damage without causing any significant disruption to our operations. The squirrel cage induction generator operates by utilizing windings on both the stator and rotor parts. It comprises three windings configured in either a star or delta connection as per our specific requirements.

Therefore, having considered all these essential aspects and carefully evaluated all available options, we confidently conclude that the squirrel cage induction generator is undoubtedly the right choice for us due to its affordability, simplified structure, ease of maintenance and replacement

- **Energy Generation Theory**
  Ferraris' theorem is a fundamental concept in electrical engineering that explains how the creation of a rotating magnetic field is possible in a machine with sliding speed relative to the stator. The rotation of this field imparts on the rotor a mechanical speed represented by $\omega r=d\theta dt$, where θ corresponds to the angle between the windings of the stator and rotor. Since there exists relative motion between the rotating magnetic field and rotor, every closed loop of conductors in the rotor experiences a variable voltage induced, whose magnitude is dependent on Faraday's law and linked to $\boldsymbol{\Phi}s$ (the stator flux). In essence, Ferraris' theorem highlights how electromagnetic forces can be harnessed to generate motion within electrical machines.

Chapter 4

System Design

4.1 System Architecture

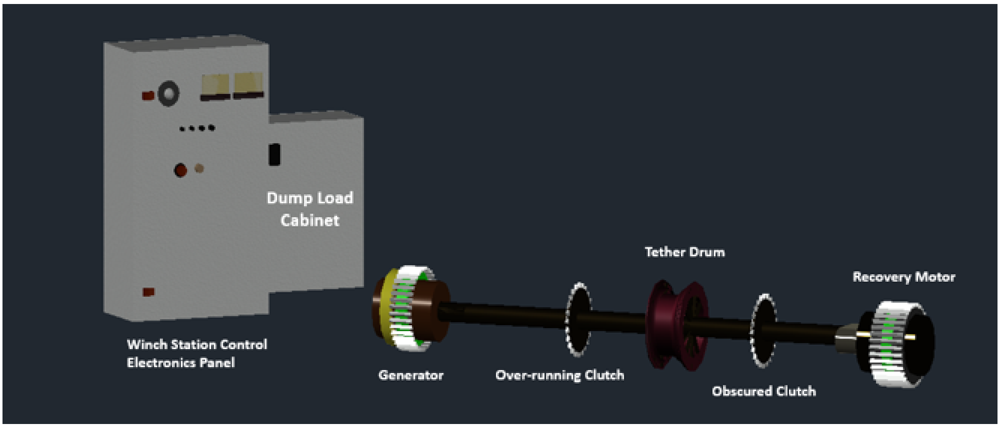


Figure 4.1: Ground Winch System

Our innovative design for the Electric Kite or Airborne Wind Energy System (AWES) is composed of two distinct segments: the ground station and the kite system. The ground station plays a critical role in generating electricity and comprises essential components such as a driveshaft that houses both a drum generator and a recovery motor on either end. Furthermore, it includes a tether drum equipped with clutches designed to regulate the speed of rotation during reel-out phases, along with a winch control station complete with all necessary circuitry required to oversee and govern the kite system's operation. This winch control station contains crucial features like voltage displays, start/stop buttons, among others. Additionally, it has been paired with an efficient dump load system to ensure smooth functioning.

The kite system component of our model includes an advanced parafoil kite connected via tether ropes firmly wound around the aforementioned tether drum. These ropes pass through vertical anchors that are strategically hoisted into the ground for maximum stability during operation.

4.2 Design Constraints

Airborne wind energy systems (AWES) hold a lot of promise as a more cost-effective alternative to traditional wind turbines, at least in theory. However, the commercialization of AWES is still hindered by several design and engineering challenges that need to be addressed. One major hurdle is choosing an electrical drive that is both highly efficient and fault-tolerant, especially for AWES designs that rely on reel-in/out for power generation. While AWES may offer cost savings over traditional wind turbines, their off-the-shelf construction components can make them more susceptible to failure and frequent replacement. As such, maintenance requirements remain the primary limitation of AWES technology, particularly when it comes to large-scale implementation. Overall, while there are certainly benefits to using AWES for generating renewable energy, addressing these practical constraints will be key to realizing its full potential.

4.2.1 Controlling Kit

4.2.2 Arduino Nano

Arduino is a hardware and software startup that is cheap and commonly used in school task

4.2.3 DC Voltage/Current Sensors

DC voltage and Current sensors are paired with the Arduino used.

4.2.4 DC Voltage Display

It is used to display the voltages measured.

4.2.5 IBT-2 Module

It is used to give high power to the motor by using a small voltage signal from a microcontroller.

4.2.6 DC Voltage Controller

A reference voltage is compared with the output voltage and the pass device is adjusted to maintain a stable output voltage.

4.3 Controllers

4.3.1 PID

PID controller is a loop control module widely used in industrial control systems and other applications. necessitating ongoing control modifications, The PID controller continues to calculate the error number as the difference between the desired setting and the approximate process variation, and utilises correction based on measurement, complete, and derivative terms (specified as P, I, and D, respectively). When it comes to assets, PID adjusts the control function automatically and precisely.

4.4 Design Methodology

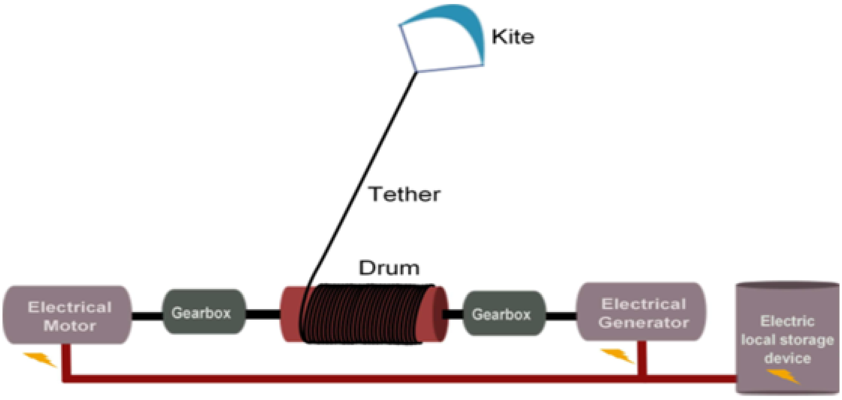


Figure 4.2: Block Diagram

Introducing our novel concept of an Airborne Wind Energy System (AWES) or Electric Kite, which is divided into two primary components: the ground station and the kite system. The electric kite assemblage relies heavily on the ground station, which plays an integral role in powering up the entire system. The ground station's primary function is to maintain complete control over the mechanism and regulate its movement, speed, and power generation. This is accomplished through servo drives that adjust the length and pace of the connector, which substantially alters mechanical currents. The driveshaft operates a drum generator and a recovery motor on either end while also hosting a tether drum with both clutches that regulate velocity during reel-out phases. Additionally, the winch control station located at the ground terminal comes equipped with all necessary circuitry for operating every aspect of this AWES including essential components like start/stop buttons as well as voltage displays. A dump load installed within these components manages excess energy and ensures optimal performance under all conditions.

The second part of our proposed model consists of a parafoil kite along with tether ropes, referred to as the kite system. This portion gets wound around a tether drum passing through an anchored vertical hoist securely fixed in place upon sturdy grounds. Together this design allows for maximum wind absorption by utilizing significant altitude advantages combined with unobstructed airflow patterns to extract more potential energy from highaltitude winds than any traditional horizontally based wind turbine could ever hope to achieve!

4.5 High Level Design

- **Ground Control Station** When the energy Kite is not in flight, it rests at the base station, which also retains the tether. Traditional wind turbines take up a lot of room on the ground, but the ground station takes up a lot less. The length of the tether to which the Kite may be tied is determined by the ground station's strength. It is also home to the basic working elements of the electric kite such as generator, clutch, tether drum and recovery motor. Also, the main control box and controls are housed there.

- **Ground Winch Station** The electric kite assembly is an intricate machine that relies heavily on its main station to control its movement, speed, and power generation. The main station plays a crucial role in ensuring the proper functioning of this complex system. To achieve this, servo drives are employed to regulate the length and speed of the connector, ultimately altering the mechanical current. This allows for precise adjustments to be made to ensure that everything operates smoothly.

  The fastener, which is responsible for attaching the kite securely to the hook at the top of the drum, is carefully aligned with the fairing.

The prototype drivetrain has three drive shafts: a low-speed main shaft with a connecting drum mounted on it; a high-speed recovery and braking shaft; and a highspeed power shaft. In case of an emergency stoppage, an electromagnetic brake provides quick stopping capabilities while allowing aircraft flight at a fixed length.

To provide power to the hook, a single-phase AC 220 V supply is sourced from either electricity or a portable generator. Taking necessary precautions concerning electrical safety devices ensures safe operation of the electrical system. A low-level human interface is provided through front panel access that enables easy interaction with specific aspects of hook operations.

In emergency situations requiring immediate cessation of activity in progress, activation of the emergency stop button quickly halts recovery engine operation by applying electromechanical brakes and opening generators fully. Regenerative recovery function is achieved using a threephase induction motor connected to variable frequency drives (VFD) rather than conventional means.

4.5.1 Process

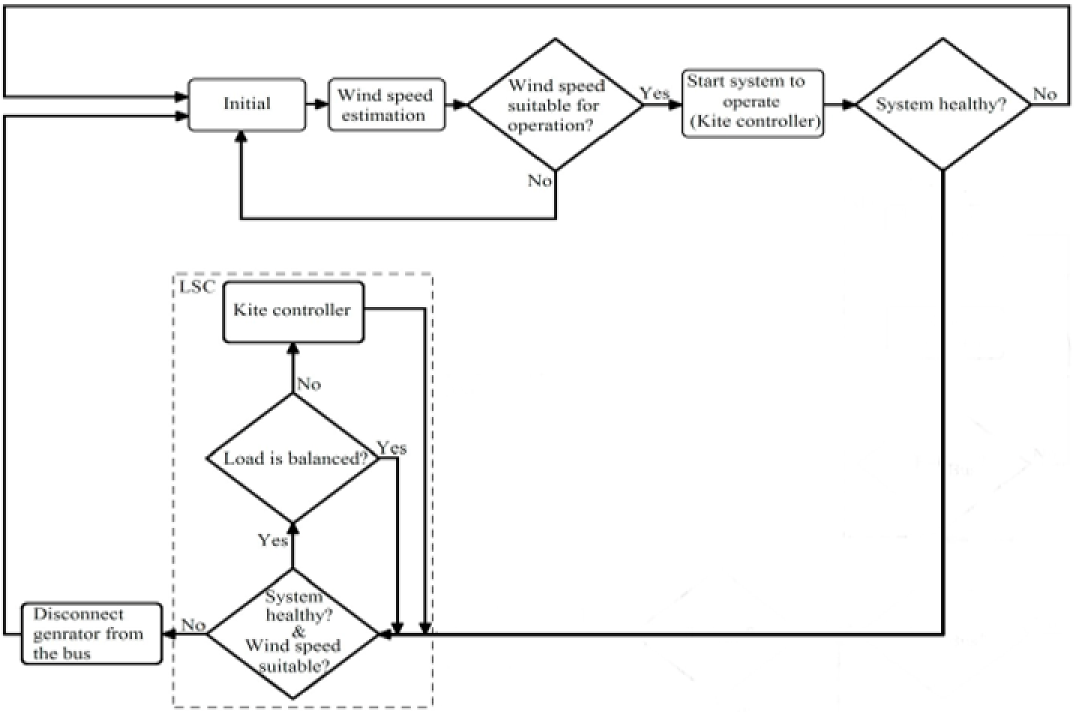


Figure 4.3: Process Flow of Electric Kite

Following is the flow diagram of the the Final Annual project ”Electric Kite” which represents the process flow of the working.

4.5.2 Hardware

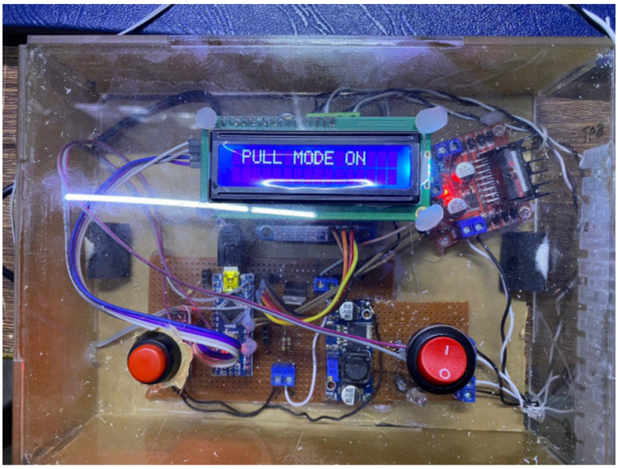


Figure 4.4: Arduino Nano paired with IBT-2 Module and voltage-current sensors in Control Box Unit during Pull Mode.

Figure 4.5: During Power Mode.

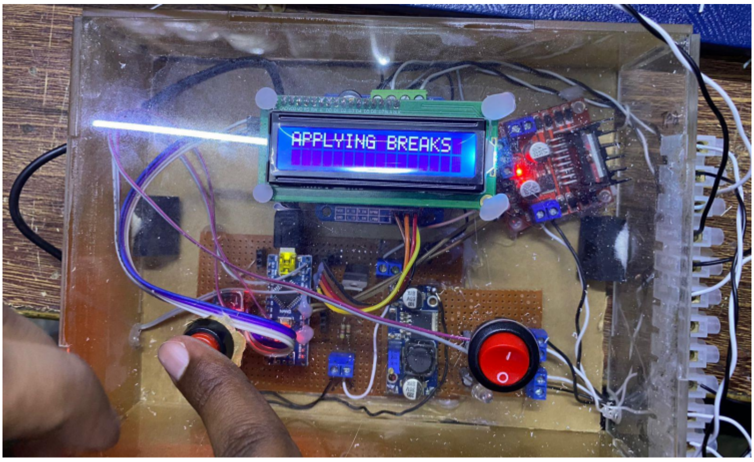


Figure 4.6: During Breaking Mode.

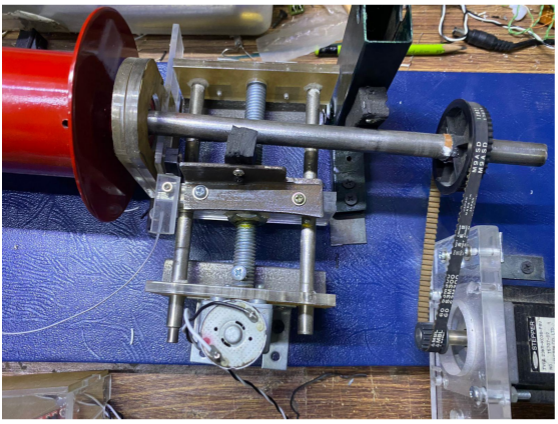


Figure 4.7: The Braking Unit, during Braking Mode.

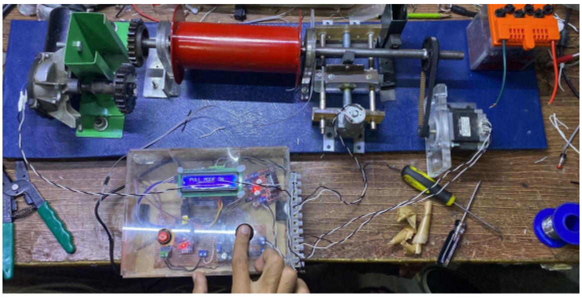


Figure 4.8: Ground Control System along with Control Unit Box.

4.5.3 Arduino Nano

High processing speed, ease of reprogramming compared to other controllers, and compatibility with the C and C++ programming languages via a standard API (also referred to as the Arduino Programming Language) are reasons why it is commonly utilized.

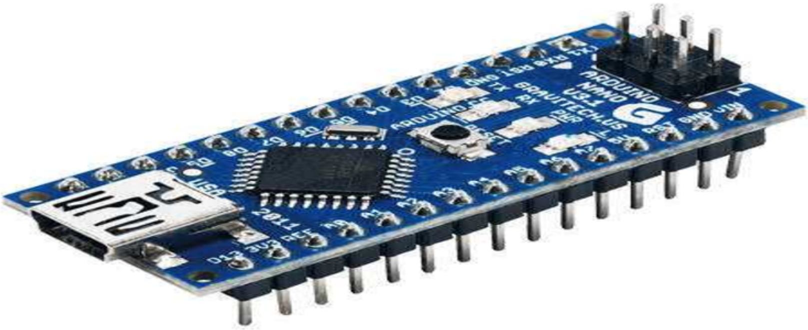


Figure 4.9: Arduino Nano

4.5.4 Battery

In our project we are using a 12-volt which will be used to store the electricity generated. After that we are running DC load. We give our 12-volts battery input to the inverter that will convert them to the 220v AC and lighten our bulb.

Figure 4.10: 12-volt battery.

4.6 Low Level Design

Our proposed model of an Electric Kite or Airborne Wind Energy System (AWES) consists of two primary components: the ground station and the kite system. The ground station is an essential part of this electric kite system, as it houses all the necessary equipment for generating electricity. It operates by regulating and controlling every aspect of movement, speed, and power generation within the entire assembly. To facilitate this regulated control, servo drives are used to alter mechanical current thereby controlling both length and speed of the connector. The fairing ensures that there's proper alignment of the fastener with hook on top of drum while the clutch drum has an overdrive clutch lever radius arm which converts clutch tension into mechanical torque on the driveshaft.

Additionally, a tether drum is mounted onto one end of the driveshaft while at its other end sits a drum generator and a recovery motor. There are also both clutches installed in this area which help regulate rotation velocity during reel-out phase. All these components work together to ensure optimal functioning and electricity generation from our proposed model. The ground station also comes equipped with a winch control station containing necessary circuitry to regulate kite system operations such as a start/stop button, voltage displays, dump load etc.

On the other hand, we have the kite system itself consisting primarily of parafoil kites along with tether ropes wound around tether drums passing through vertical anchors hoisted firmly into place within different points on ground terrain.

Overall, our proposed Electric Kite System or AWES boasts impressive design and functionality aimed at revolutionizing energy generation industry worldwide!

Chapter 5

System Implementation

The main architecture of our system is divided between the various motors used, of which the first one is the “pull motor” which is being controlled by the IBT-2 module and it supports up to 40 Amps of current. Initially the current value is set low, so that our battery is drained less. The initial pulse width modulation (PWM) is set at 70 and can be increased up to 255. The IBT-2 is given power through the battery and is also connected to the Arduino nano by four control pins which are namely:

- Left PWM
- Right PWM
- Left Enable
- Right Enable

The enable pins are used to give power to the module and the PWM pins are used to control the direction of the pull motor. All the functions are controlled by the on/off switch on the control unit box along with the breaking control. The breaking unit is powered by a smaller motor driver L298 and limit switch is used to send signal to the Arduino for when the brake is applied or removed. The other mode used to charge the battery is the ”generator mode” which takes AC input from the generator and converts it into DC input and a booster is used to increase the voltage and charge the battery. The voltage and current generated are displayed on the LCD.

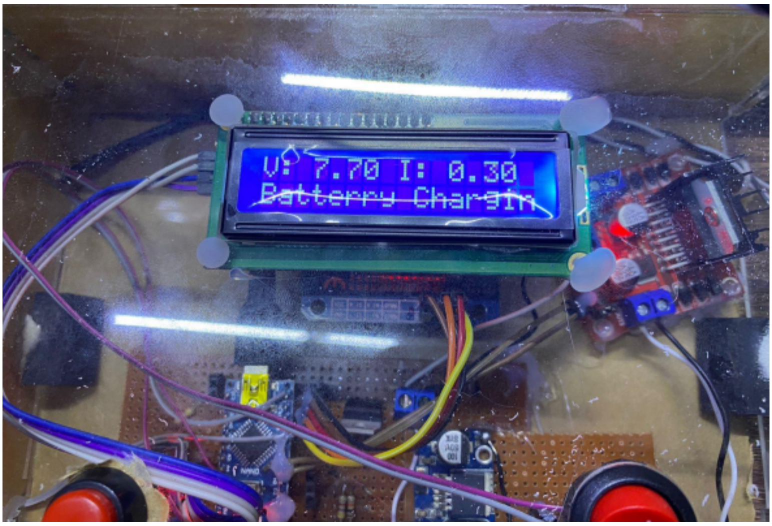


Figure 5.1: LCD during battery charging mode.

To take things to the real world we must be more realistic, and we must face all the challenges and uncertainties to achieve our goal. When we designed the system, we kept the natural elements in our mind. The wind is not always reliable and may vary in time and weather, so we should do a test to prepare for our project.

5.1 System Architecture

5.1.1 Arduino Source Code

This is a generic code our objective is to program the Arduino in such a way that it will take specific inputs from the Kite System.
After programming and connecting the Arduino, we must check the DC voltage and current sensors if they are in working order. For that, we have used specific sensors to record the voltage and current to differentiate between the working on desired input values. To view the output, we used

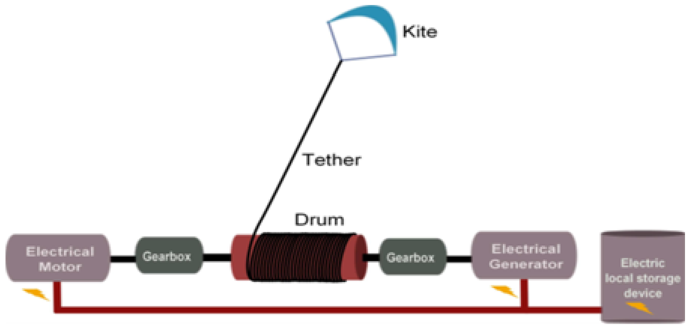
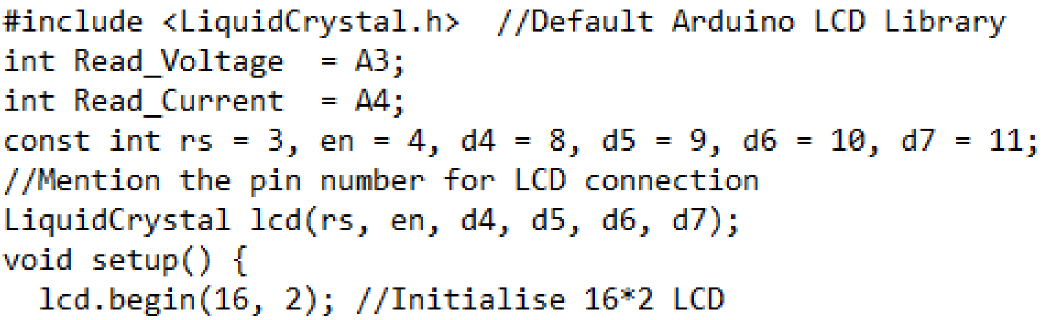
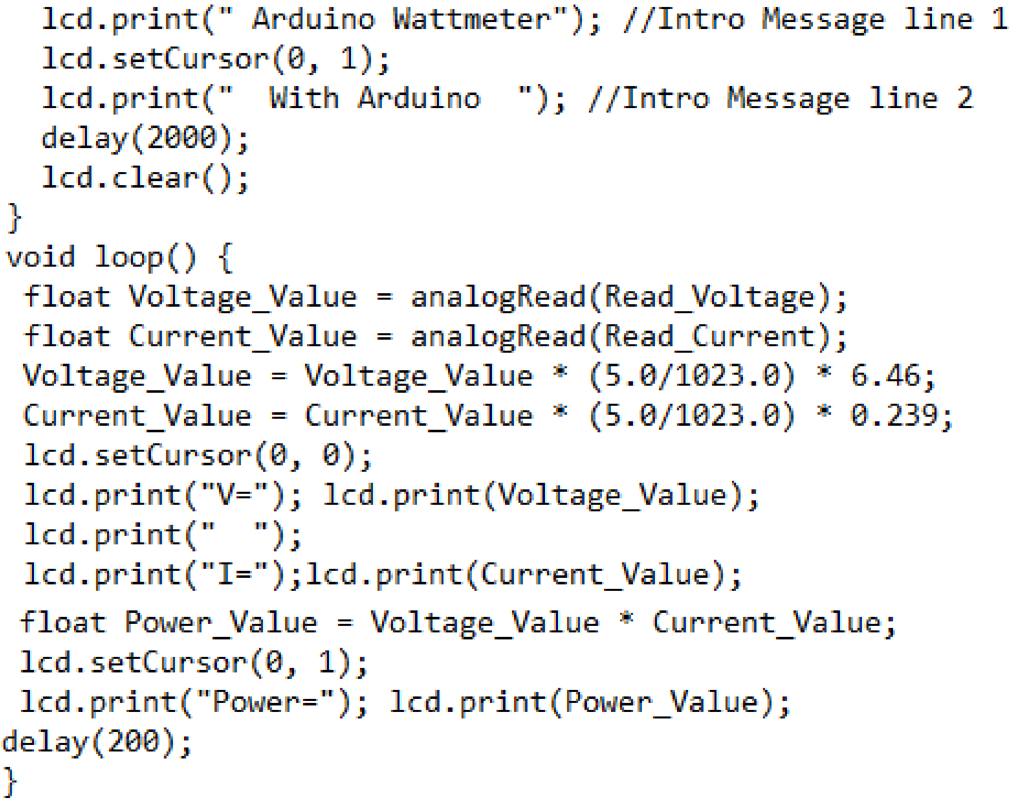


Figure 5.2: Block Diagram.

an LCD.



```
#include <LiquidCrystal.h>  //Default Arduino LCD Library
int Read_Voltage  = A3;
int Read_Current  = A4;
const int rs = 3, en = 4, d4 = 8, d5 = 9, d6 = 10, d7 = 11;
//Mention the pin number for LCD connection
LiquidCrystal lcd(rs, en, d4, d5, d6, d7);
void setup() {
  lcd.begin(16, 2); //Initialise 16*2 LCD
```



```
  lcd.print(" Arduino Wattmeter"); //Intro Message line 1
  lcd.setCursor(0, 1);
  lcd.print("  With Arduino  "); //Intro Message line 2
  delay(2000);
  lcd.clear();
}
void loop() {
 float Voltage_Value = analogRead(Read_Voltage);
 float Current_Value = analogRead(Read_Current);
 Voltage_Value = Voltage_Value * (5.0/1023.0) * 6.46;
 Current_Value = Current_Value * (5.0/1023.0) * 0.239;
 lcd.setCursor(0, 0);
 lcd.print("V="); lcd.print(Voltage_Value);
 lcd.print("  ");
 lcd.print("I=");lcd.print(Current_Value);
 float Power_Value = Voltage_Value * Current_Value;
 lcd.setCursor(0, 1);
 lcd.print("Power="); lcd.print(Power_Value);
delay(200);
}
```

5.1.2 Tools and Technology Used

- Arduino Nano
- IBT-2 Module
- DC Voltage & Current Sensors
- Programming in C
- LCD Display
- Acrylic Box
- Veroboard
- DC Voltage Display
- DC Motor 12-volt
- Gear Motor 5-amp
- Generator Motor 24-volt
- Gear Mounting
- Motor Coupling

5.1.3 Languages Used

Flow chart model for the project include Arduino which has been coded according to our objective

Chapter 6

System Testing and Evaluation

The main structure of the system is centred around the various motors applied. The initial motor used is what we refer to as the ”pull motor.” It holds a capacity of up to 40 Amps of current, and it’s managed by the IBT-2 module. To conserve battery power, we start with low current values. We use pulse width modulation (PWM) to control the pull motor; this involves an initial PWM value of 70 that can be increased up to 255. The IBT-2 module draws its energy from the battery and links it to the Arduino nano through four control pins: Left PWM, Right PWM, Left Enable, and Right Enable. The purpose of these pins is such that power flows into the module via enable pins while PWM pins regulate the direction in which the pull motor moves.

The system functions are managed by both an on/off switch and breaking control unit.

A smaller L298 motor driver powers the braking unit whereby a limit switch alerts the Arduino when there is engagement or disengagement of brakes.

We have integrated a ”generator mode” function in our design which allows us to charge our batteries using AC power input via a generator that converts AC input into DC output. A booster increases voltage levels for efficient battery charging purposes. Our LCD displays generated voltage and current information.

Field trials were conducted across several different sites under varying wind conditions. To allow for speedy deployment with minimal logistical requirements, our system was designed to operate without needing electrical winches when necessary, during flight tests setups.

During field testing setups:

- Wind speed/direction are cross-checked where layout setup depends on wind direction aligning with anchor direction.
- A secure soil anchor removes vertical force from cords
- Another anchor furthers ground control security
- Cord-kite fastening before flight is secured
- Kite lines are then spread out
- Powering/testing control unit box

The experiment was conducted to evaluate the effectiveness of a project and observe its operational output under various environmental conditions. The test persisted for an entire day, during which all relevant factors such as temperature, humidity, and wind speed were taken into consideration. In addition to analysing the system's performance, the research aimed to determine the ideal working window where the project would operate at maximum efficiency. An essential aspect of this study was also examining how changes in wind conditions affected the overall functioning of the system. All these detailed observations will enable researchers to make informed decisions about future improvements or modifications required for optimum performance.

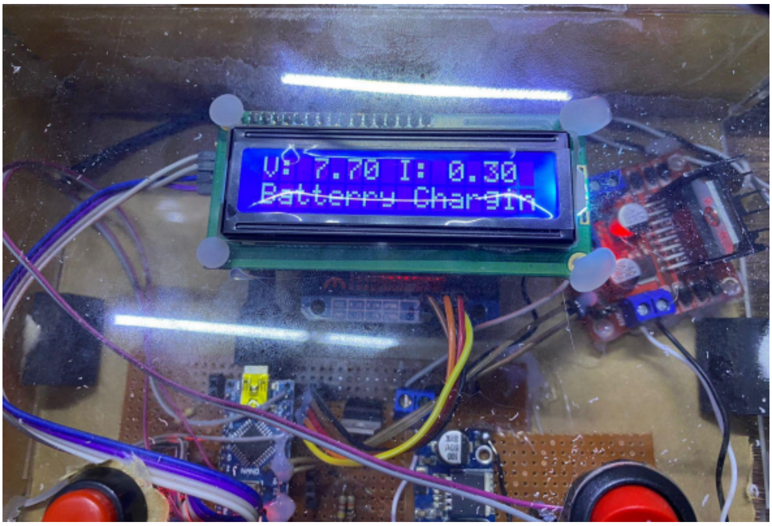


Figure 6.1: LCD during battery charging mode.

After a thorough analysis of the project, we have determined that the efficiency of our system is directly related to the wind speed and the location. Specifically, we observed that when the wind speed exceeded 15 kmph in open plains, our system produced a maximum output from the energy source. As a result of these observations, we decided to program our Arduino and its battery modules around this optimal range to ensure that we extract as much energy as possible from the wind. It is important to note that this optimization process will ultimately lead us towards achieving efficient energy production which can be utilized in multiple ways for different applications.

Chapter 7

Conclusion

The potential of the electric kite project to transform the way we generate sustainable energy cannot be overstated. By utilizing high-altitude kites or airborne wind energy systems, we can harness wind power in a more efficient and reliable manner, since wind speeds are greater and more consistent at higher altitudes. To optimize efficiency and minimize power consumption, the system's architecture incorporates various motors, controllers, and generators that have been meticulously designed. Despite significant technical and practical challenges that lie ahead, such as developing strong and durable materials for constructing kites as well as advanced control algorithms that can adjust to changing weather conditions, it is clear that electric kites hold much promise for achieving a cleaner future.
In our research on this subject matter, we delved into different programs used within the industry like Arduino. We experimented with various codes for programming Arduino to design an efficiently working code suitable for managing battery/voltage systems. Through careful analysis of specifications related to generator and pull motors for drivetrain along with control unit specifications including assessment of their respective pros and cons enabled us to design a working prototype. Our Final Year Project was designed with the goal of becoming a reliable power supply source for individuals seeking independence by generating their own electricity.
After conducting thorough testing on our prototype device which yielded about 20-volts of power output - sufficient enough to provide sustainable power - we conclude that electric kites offer far greater efficiency than traditional methods of wind energy generation; which can be expensive due to their heavy reliance on costly infrastructure such as turbines or other bulky equipment. The electric kite project represents an excellent investment opportunity whereby costs associated with conventional electricity usage can be recovered in just one-time payment through independent generation

using this technology.

Chapter 8

References

Bibliography

[1] The Social Acceptance of Airborne Wind Energy: A Literature Review by Helena Schmidt, Gerdien de Vries , Reint Jan Renes and Roland Schmehl.

[2] High altitude wind energy generation using controlled power kites Massimo Canale, Member, IEEE, Lorenzo Fagiano, Member, IEEE, Mario Milanese, Senior Member, IEEE.

[3] Airborne Wind Energy System Harshit Surya Koppisetti, Archana Mangalagiri, Chandrashekar Rayanki.

[4] 4-Airborne Wind Energy Systems: A review of the technologies by Antonello Cherubini, Andrea Papini, Rocco Vertechy, Marco Fontana.

[5] Lansdorp B, Ockels WJ. Comparison of concepts for high-altitude wind energy generation with ground-based generator. In: The second

China international renewable energy equipment & technology exhibition and conference, Beijing, China, 2005.

[6]] Gulabani, G.; Karim, B.S.A.; Radhakrishnan, J.; Satish, B.S.; Zuber, M. Review on Unconventional Wind Energy. J. Eng. Technolg.Sci. 2020, 52, 565–583.

[7] Archer, C. (2013). An introduction to meteorology for airborne wind energy. In U. Ahrens,M. Diehl, & R. Schmehl (eds.)

[8] Airborne wind energy (pp. 81–94). Berlin: Springer.

[9] Archer, C., & Caldeira, K. (2009). Global assessment of highaltitude wind power. Energies, 2, 307–319

[10] Argatov, I., Rautakorpi, P., & Silvennonien, R. (2011). Apparent wind load effects on the tether of a kite power generator

[11] Journal of Wind Engineering and Industrial Aerodynamics, 99, 1079–1088

[12] Argatov, I., & Silvennoinen, R. (2010). Energy conversion efficiency of the pumping kite wind generator. Renewable Energy, 35, 1052–1060

[13] Boike, J., & Yoshikawa, K. (2003). Mapping of periglacial geomorphology using kite/balloon aerial photography. Permafrost and Periglacial Processes, 14, 81–85

[14] Bormann, A., Maximilian, R., K¨ovesdi, P., Gebhardt, C., & Skutnik, S. (2013). Development of a three-line ground actuated airborne wind energy converter. In U. Ahrens, M. Diehl, & R. Schmehl (eds.), Airborne wind energy (pp.427–436). Berlin: Springer

[15] Bosman, R., Reid, V., Vlasblom, M., & Smeets, P. (2013). Airborne wind energy tethers with high-modulus polyethylene fibres. In U. Ahrens, M. Diehl, & R. Schmehl (eds.), Airborne wind energy (pp. 563–585). Berlin: Springer

[16] Coleman, J., Ahmad, H., Pican, E., & Toal, D. (2014).Modelling of a synchronous offshore pumping mode airborne wind energy farm. Energy, 71, 569–578

[17] Dongwon, J., & Tsiotras, P. (2007). Inertial attitude and position reference system development for a small UAV. AAIA Infotech at Aerospace. Rohnert Park, CA: American Institute of Aeronautics and Astronautics

[18] Erhard, M., & Strauch, H. (2013). Control of towing kites for seagoing vessels. IEEE Transactions on Control Systems Technology, 21, 1629–1640

[19] Fechner, U., & Schmehl, R. (2012). Design of a distributed kite power control system. IEEE International Conference on Control Applications,Dubrovnik, Croatia

[20] Milanese,M., Taddei, F., & Milanese, S. (2013). Design and testing of a 60 kW yo-yo airborne wind energy generator. In U. Ahrens, M. Diehl, & R. Schmehl (eds.), Airborne wind energy (pp. 373–386). Berlin: Springer

[21] Fritz, F. (2013). Application of an automated kite system for ship propulsion and power generation. In U. Ahrens, M. Diehl, & R. Schmehl (eds.), Airborne wind energy (pp. 359–372). Berlin: Springer

[22] van der Vlugt, R., Peschel, J., & Schmehl, R. (2013). Design and experimental characterization of a pumping kite power system. In U. Ahrens, M. Diehl, & R. Schmehl (eds.), Airborne wind energy (pp. 403–425). Berlin: Springer

[23] Jehle, C., & Schmehl, R. (2014). Applied tracking control for kite power systems. J. Guidance, Control and Dynamics, 37, 1211–1222

[24] Lingard, S. J. (1995). Ram-air parachute design. 13th AIAA Aerodynamic Decelerator Systems Technology Conference. Clearwater Beach, FL

[25] Motor,Maxon (2012). Program 2012/13: High Precision Drives and Systems. Sachseln

[26] D. Q. Mayne, J. B. Rawlings, C. V. Rao, and P. Scokaert, "Constrained model predictive control: Stability and optimality," Automatica, vol. 36, pp. 789–814, 2000

[27] Description and preliminary test results of a six degrees of freedom rigid wing pumping system. In U. Ahrens, M. Diehl, & R. Schmehl (eds.), Airborne wind energy (pp. 443–458). Berlin: Springer

[28] Murray, J., Neal, M., & Labrosse, F. (2013). Design and deployment of an intelligent kite aerial photography platform (iKAPP) for site surveying and image acquisition. J. Field Robotics, 30, 288–307

[29] Development and Testing of a Control System for the Automatic Flight of Tethered Parafoils by Joseph Coleman, Hammad Ahmad, and Daniel Toal