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Portable Wind Power Charger

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Abstract

This project presents the development of a lightweight and portable wind-powered generator designed to provide off-grid charging for small electronic devices in outdoor or emergency environments. The system includes a compact wind turbine and a manual hand-crank mechanism to ensure power generation even when wind is limited. A 3D-printed planetary gear system connects the turbine to a DC generator, enabling effective energy capture at lower wind speeds. Power is regulated through a two-stage system consisting of a boost converter and a buck converter, delivering a consistent 5V USB output for user devices. The overall unit weighs approximately three pounds and is designed for simple field assembly and weather resistance. Testing showed that the system begins generating power at wind speeds with output voltages consistently 5.0V. Comparative blade testing revealed that curved blades offer improved performance and faster startup in low-wind conditions. The final design supports outdoor recreation, disaster relief, and remote work by providing a reliable, renewable alternative to traditional battery-based or solar-only solutions.

Acknowledgements

We would like to express our sincere gratitude to everyone who supported us throughout the development of this project.

We are especially grateful to Dr. Greenwood, whose guidance was instrumental in our understanding of physical principles, simulation work, and testing of electrical components. His insights helped shape both our system performance and technical understanding. We also extend special thanks to Dr. Integlia and Dr. Elg for their continued mentorship and support throughout each phase of development.

Special thanks go to Justin Amos at the Applied Engineering Center (AEC), whose expertise with fabrication tools and materials greatly improved our build process. We also thank Dr. Chlebowski for his help during the 3D printing phase, which was essential to creating our prototypes.

We appreciate the research assistance provided by Mr. Shane White at the Rice Library, whose help was key to gathering technical references.

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1. Background

The rapid growth of outdoor recreation, humanitarian engineering, and off-grid operations has driven demand for sustainable, portable power solutions. Activities such as camping, hiking, and remote infrastructure development increasingly depend on electronic devices—phones, GPS units, lighting systems, and sensors—for safety, communication, and monitoring. In 2022 alone, outdoor participation in the U.S. increased by 2.3%, reinforcing the need for compact, field-ready power systems [1].

Current market solutions primarily revolve around solar-powered chargers, which are simple, renewable, and relatively efficient under ideal sunlight conditions. These products, valued at USD 515.8 million in 2023, are forecasted to grow at a CAGR of 14.1% [3]. However, solar chargers become ineffective in shaded forests, cloudy environments, or nighttime situations. To address this limitation, wind and hybrid systems have been introduced. For example, the Shine Turbine offers 40W in a 1.3 kg package [4], and the WaterLily hybrid generator delivers 15W through either wind or water input [6]. Despite their innovations, these systems often lack low-wind startup capability, present mechanical complexity, or face uncertain long-term availability [7].

Our project addresses this gap by designing and constructing a **Portable Wind Power Charger (PWPC)**—a lightweight, durable, and collapsible wind energy generator capable of charging small devices via a USB-C output. The system includes a DC generator, a 3D-printed planetary gear train to enable energy harvesting from low wind speeds, and a two-stage voltage regulation circuit. The entire assembly fits within 7.56 liters, weighs approximately 3 pounds, and can be field-assembled in under ten minutes.

A key innovation in this design is the use of interchangeable turbine blades, allowing adaptation to environmental conditions. Two blade types were tested: square blades, which deliver higher torque at strong wind speeds but suffer drag-related startup lag, and curved blades inspired by aerodynamic airfoils, which offer smoother rotation and superior low-wind performance [8], [9], [14]. SolidWorks simulations (see Figure 9) and physical testing confirmed the curved blade design enables faster startup at wind speeds as low as 5 mph, improving energy consistency in variable outdoor conditions.

The generator system is paired with a dual-stage power conditioning circuit: a boost converter increases the raw generator output (starting at ~3V), while a buck converter stabilizes the final output to a clean 5.0V DC. Testing across resistive loads (10Ω to 100Ω) and live USB charging scenarios validated the system's performance, with voltage consistently maintained between 4.8V and 5.0V. Start-up torque was experimentally measured at 0.0068 Nm, confirming suitability for portable, low-inertia applications.

From an engineering perspective, each subsystem is guided by recognized standards, including IEC 61400-2 for small wind turbine design, ISO 14001 for sustainable development, and IEEE 1547 for renewable system integration [24]–[26]. Additional compliance with FCC Part 15 ensures electromagnetic compatibility of sensor modules and digital interfaces [27].

The broader impact of this design extends beyond outdoor recreation. Portable, renewable systems such as the PWPC support emergency disaster relief operations, military field communications, and community development projects in electricity-scarce regions [13], [16], [17]. By reducing dependence on disposable batteries or gasoline-powered generators, the system also supports environmental and sustainability goals outlined in global energy policy frameworks [23].

This project demonstrates that through optimized blade geometry, modular design, and effective voltage regulation, a compact wind generator can reliably deliver power in remote environments. The following sections describe the system's design, testing, and evaluation in detail.

2. Objective Statement

The goal of this project is to design and construct a lightweight, portable wind-powered generator capable of reliably charging small electronic devices in off-grid environments. The system must operate under variable wind conditions and initiate power generation at wind speeds as low as 5 mph. Key performance objectives include delivering a stable 5V USB output and maintaining voltage between 4.8V and 5.0V across a range of electrical loads. The generator must be compact enough for backpack transport, require minimal assembly time, and meet environmental durability standards for outdoor use. The project emphasizes practical usability, sustainability, and adaptability, targeting applications such as outdoor recreation, disaster response, and remote field operations.

3. Stakeholders.

The success of the Portable Wind Power Charger depends on meeting the expectations and requirements of several key stakeholders. Dr. Integlia, serving as our faculty advisor and domain expert, provides technical oversight and ensures that the project adheres to academic and engineering standards. His feedback has guided system integration, component selection, and performance evaluation.

The project also draws direct influence from Engineers in Action (EIA), a nonprofit organization involved in bridge construction and infrastructure support in remote communities. EIA field engineers require reliable, off-grid power sources to operate communication devices, sensors, and lighting during extended field deployments. Their needs for portability, weather resistance, and consistent output directly shaped the functional requirements of our system.

Additionally, former members of the USI Outdoor Club offered valuable input during early development stages, providing user-level insights on setup time, terrain adaptability, and real-world usability for backpackers and hikers. These stakeholder perspectives ensured that the final product remains both technically sound and practically useful across a range of off-grid applications.

4. Design Restrictions, Requirements, and Constraints

The design of the Portable Wind Power Charger (PWPC) is governed by a series of safety standards, operational limits, environmental considerations, and ethical design obligations. These parameters are not only intended to ensure effective and efficient performance in real-world off-grid settings but also to guide responsible engineering practices in compliance with modern standards and regulations. The subsections below detail the guiding constraints and expectations that shaped the system's development.

4.1. Safety and Design Restrictions

To ensure safety and environmental compliance, the turbine shall meet ISO 14001 and IEC 61400 standards, which are internationally recognized benchmarks for environmental management and wind turbine safety, respectively [24]. Adhering to these standards is essential for minimizing the environmental impact of the device and ensuring its safe operation in outdoor settings. Additionally, all mechanical and electrical components shall be securely enclosed to prevent injury from accidental contact or part detachment during use, particularly in unpredictable weather conditions.

4.2. Functional Requirements

As part of its physical design restrictions, the system shall disassemble into a maximum transport volume of 0.3 cubic feet (8.5L), aligning with constraints for pack-based deployment. Assembly shall be designed to be tool-free, using snap-fit joints and a Phillips screwdriver bit from a standard multi-tool. The reassembly process shall be intuitive and require no more than 10 minutes. For further safety, the turbine shall feature built-in protection against unsafe operation, including conditions where wind exceeds operational thresholds.

Also, the turbine shall be designed with portability as one of the primary constraints, requiring a total weight not exceeding 20 lbs to ensure ease of transport. To enhance packability, the blade assembly shall be fully disassemblable, allowing for compact storage. Additionally, the turbine shall include clear, multilingual instructions for both assembly and operation to support accessibility and safe use by a diverse range of users across different regions and language groups.

To meet the practical energy needs of outdoor users, the system must deliver between 6 and 10 watt-hours over 4–5 hours of continuous operation—sufficient to charge small electronic devices such as smartphones, GPS units, or portable lights. For modern compatibility and efficiency, the turbine shall support USB-C output connections, enabling fast and standardized charging.

4.3. Environmental and Operational Constraints

To ensure reliability in diverse outdoor environments, the turbine shall operate effectively in wind speeds ranging from 5 to 30 mph. This range covers conditions from a light breeze (around 5 mph, typical of calm outdoor settings) to strong gusts approaching the threshold of gale-force winds (near 30 mph), which are common during storms but well below the destructive levels of tornadoes or hurricanes. Supporting this operational range ensures the turbine remains functional in both mild and moderately adverse weather conditions. Additionally, the system shall withstand temperature extremes between -20°F and 120°F, enabling usage in both cold mountain environments and hot desert climates.

The turbine shall be IP57 rated for water resistance, allowing safe operation in wet conditions such as rain or dew. Materials shall be lightweight, durable, waterproof, and corrosion-resistant to support extended outdoor use without degradation. From a production standpoint, the design must also remain cost-efficient, with a target manufacturing cost of no more than $150 per unit, ensuring scalability and affordability for widespread deployment, including in emergency and humanitarian contexts.

4.4. Ethic Considerations

The development of the Portable Wind Power Charger was guided by a commitment to responsible engineering practices, public safety, environmental sustainability, and regulatory compliance. To align with ethical obligations outlined in the **IEEE Code of Ethics** and sustainability standards such as **ISO 14001**, the project prioritized safe operation, material responsibility, and transparency in communicating system limitations [21], [23].

Given the generator's intended use in natural and potentially protected environments such as state and national parks, it was designed to operate at **sound levels below 60 decibels**, in compliance with **CFR Title 36, Part 2.12**, which limits excessive noise pollution in recreational and wilderness areas [19]. Furthermore, **Part 2.13** of the same code restricts the use of equipment that poses a fire hazard during periods of elevated fire risk, prompting the design to include passive cooling systems and low-temperature electronic components to mitigate such concerns [20].

In terms of technical regulation, all electronic components were selected with electromagnetic compatibility and sustainability in mind. The **INA219 current sensor**, **AS5600 magnetic encoder**, and Raspberry Pi microcontroller module all comply with **FCC Part 15**, which governs the emission standards for electronic devices [27]. To reduce environmental toxicity, the design avoids hazardous substances restricted under the **RoHS Directive (EU 2011/65/EU)**, ensuring that all components—including the MPPT controller and display—meet modern material safety requirements [26].

A comprehensive overview of the regulatory standards and codes that informed the design process is provided in the table below.

Standard/Code/Regulation Name	Number	Context of Use in Project
IEC 61400-2: Small Wind Turbines	IEC 61400-2	Ensures design, testing, and safety compliance for small wind turbines used in the generator.
IEEE 1547: Standard for Interconnection of Distributed Resources	IEEE 1547	Guides the integration of renewable energy sources (wind turbines) with energy storage and distribution.
RoHS Directive (Restriction of Hazardous Substances)	EU Directive 2011/65/EU	Ensures all electronic components, such as Raspberry Pi and MPPT circuit, comply with environmental regulations.

FCC Part 15: Radio Frequency Devices	FCC Part 15	Ensures GPS, sensors, and other electronic modules meet electromagnetic compatibility standards.
IEC 61508: Functional Safety of Electrical/Electronic/Programmable Electronic Safety-Related Systems	IEC 61508	Ensures the safe operation of electrical, electronic, and programmable electronic systems, mitigating risks such as electrical shock, overheating, and fire, particularly in rugged outdoor conditions.
National Park Regulations: Noise and Fire Safety	CFR Title 36, Part 2.12 & 2.13	Ensures the generator operates below 60 dB to minimize environmental disruption and adheres to fire safety restrictions during bans or heightened risk periods.
ISO 14001: Environmental Management Systems	ISO 14001	Promotes sustainable development through energy-efficient product design and manufacturing processes.

Table 1. Standards that affect the generator project.

5. Project Design

The Portable Wind Power Charger (PWPC) was developed through a modular engineering approach designed to maximize performance, durability, and adaptability in varied real-world environments. The design process responded to the increasing demand for reliable and field-ready renewable energy sources, particularly in remote areas where solar power may not be feasible due to inconsistent weather or obstructive terrain. The final system was built to withstand changing wind conditions, and enable efficient assembly, operation, and maintenance by a single user with minimal tools.

The internal structure of the PWPC consists of three integrated subsystems: the structure, the turbine assembly, and the electrical regulation system. These subsystems were arranged and refined to optimize performance and ensure seamless integration. The structure is responsible for providing the frame and overall housing to the generator while supporting environmental exposure during outdoor deployment. The turbine assembly captures wind energy and transmits mechanical power through a gear system to the generator. The electrical regulation system converts and stabilizes this energy into a consistent 5V DC output, making it suitable for powering and charging consumer electronic devices.

The modular nature of the PWPC allowed for simplified fabrication, streamlined testing, and a clear separation of system functions. This approach also enabled future enhancements, such as upgrading blade geometry or integrating advanced monitoring features, without the need for redesigning the core framework. A comprehensive overview of the system's architecture, interactions, and component hierarchy is shown in the internal system block diagram, presented as Figure 1.

5.1. System diagram

The system architecture of the Portable Wind Power Charger was organized according to a hierarchical model that separates its functional operation into three primary layers: structure, turbine, and electrical regulation. This layered design simplified the prototyping process, improved system maintainability, and clarified the distinct role of each subsystem during both assembly and performance evaluation.

In the operational sequence, ambient wind first acts upon the turbine blades, causing them to rotate. This mechanical energy is then transmitted through the central shaft into a planetary gearbox located in the mechanical structure. The gearbox amplifies the rotational velocity to meet the generator's operational torque threshold, allowing electrical generation to commence at lower wind speeds. The generated raw DC voltage is routed into the power regulation circuitry, where a two-stage conversion system consisting of a boost and a buck converter processes the fluctuating voltage into a stable 5V USB output. This output is made accessible through a USB-C port integrated into the electronics housing, allowing for the direct charging of portable devices.

The system layout and modularity allow for efficient repairs and upgrades. The diagram presented in Figure 1 visually represents this architecture and its interdependent subsystems.

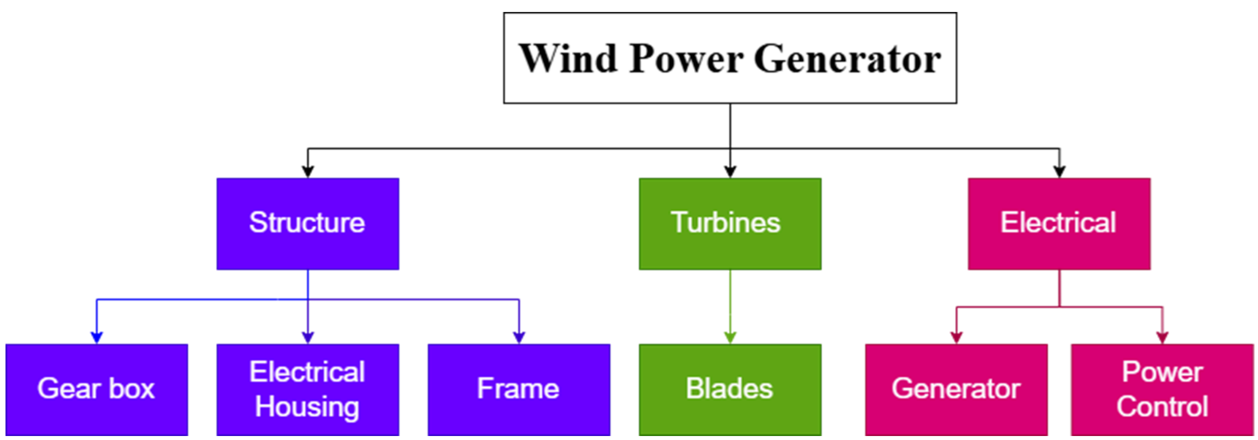

Figure 1: System Block Diagram

5.2. Structure

The structural system of the Portable Wind Power Charger was designed to be lightweight, durable, and easily deployable in a variety of field environments. The structure serves as the backbone of the device, supporting both mechanical and electrical subsystems while maintaining system stability during operation in variable wind conditions as seen in Figure

2. It was designed with portability, ease of assembly, and weather resistance as top priorities, ensuring the entire generator can be transported and set up by a single user without the need for specialized tools.

The overall frame is organized into three vertical tiers: the top-mounted enclosure for the electrical system and generator, the midsection containing the planetary gearbox, and the base structure that supports the turbine hub and legs. Each of these components was fabricated using 3D-printed parts made from PLA filament, selected for its favorable strength-to-weight ratio and printability.

The frame utilizes snap-fit prismatic legs that attach to a triangular base ring, forming a tripod-style foundation. Each leg terminates in a hook-shaped anchor designed to interface with standard tent stakes, allowing the generator to remain stable during wind gusts of up to 30 mph. The system's assembly requires no specialized tools and can be completed in under ten minutes using a standard multi-tool with a Phillips screwdriver bit or gerber. This meets the project's constraint for quick field deployment.

At the base of the turbine shaft, a rollerblade bearing was installed to provide smooth, low-friction rotation and to support the vertical load of the spinning components. This bearing interface improved stability and reduced mechanical wear during testing. The top-mounted enclosure was designed to be water-resistant and protects the generator and voltage regulation circuit from environmental exposure. It also assists with elevating the sensitive components away from moisture-prone surfaces such as wet grass or snow.

The assembled structure occupies a packed volume of approximately 7.56 liters and weighs roughly three pounds, making it suitable for backpack transport. Field testing confirmed that the generator remained upright and functional in varied terrain and weather conditions, validating the structure’s effectiveness for outdoor deployment.

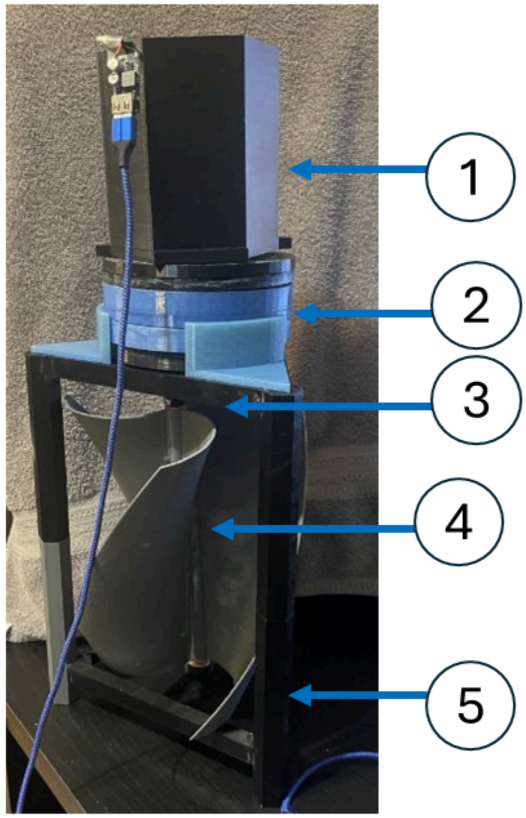

Figure 2: Deployed structure showing 1. Electronics housing, 2. Gearbox, 3. Horizontal Cross Beams, 4. Curved Blades, 5. Support legs.

5.2.1. Gearbox

A central mechanical component of the Portable Wind Power Charger is the custom-designed planetary gearbox as seen in Figure 3, which was implemented to amplify shaft speed and improve power generation from moderate wind conditions. Wind turbines of this scale often struggle to reach the rotational thresholds needed for voltage output, especially when relying on direct-drive mechanisms. To address this challenge, the team designed a modular, multi-tiered planetary gear system intended to progressively increase rotational speed through stacked mechanical stages.

Figure 3: Planetary gear assembly showing sun (black), planet (blue gear), ring gear (black ring), and box of gear

Each stage of the gearbox consists of a sun gear connected to the turbine shaft, three planet gears rotating on a carrier, and an outer ring gear as seen in Figure 3. The gear stages were vertically stacked, forming a compact transmission system that increased output speed without increasing lateral dimensions. This tiered stacking allowed for a higher overall gear ratio, with each layer contributing incremental speed gain. The modular construction also supported easier prototyping and adjustments throughout the testing process.

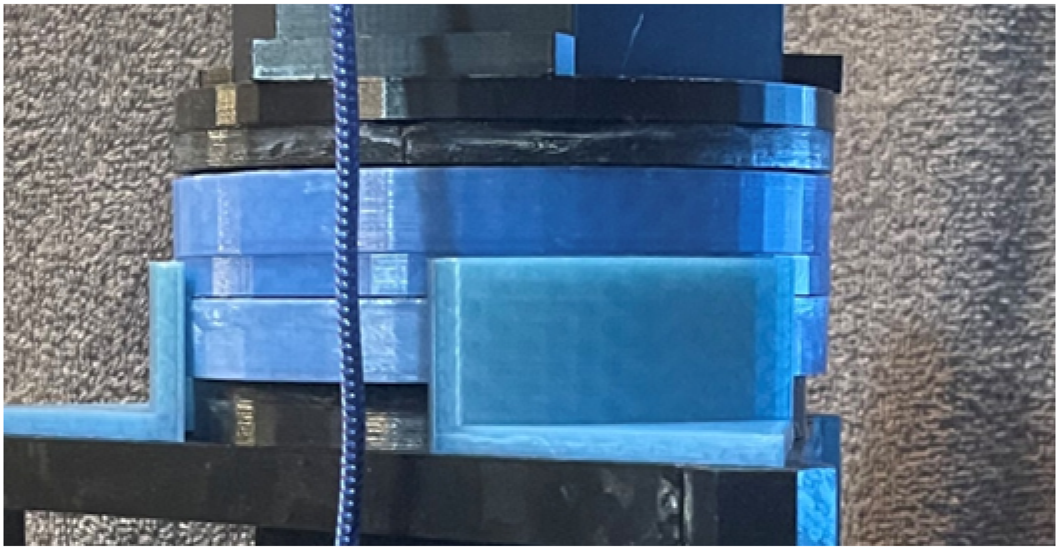

Figure 4: Two planetary tiers stack above one another.

The gearbox was designed in SolidWorks and printed using PLA to allow for accessible, rapid prototyping. While the structure maintained alignment during operation, friction within the gear teeth and between printed contact surfaces emerged as a performance limitation. Despite the intended amplification, rotational resistance from imperfect gear meshing and material deformation inhibited startup at lower wind speeds. A rollerblade bearing was installed at the base of the gearbox to provide vertical support and reduce axial friction, which improved rotational stability but did not fully eliminate startup drag.

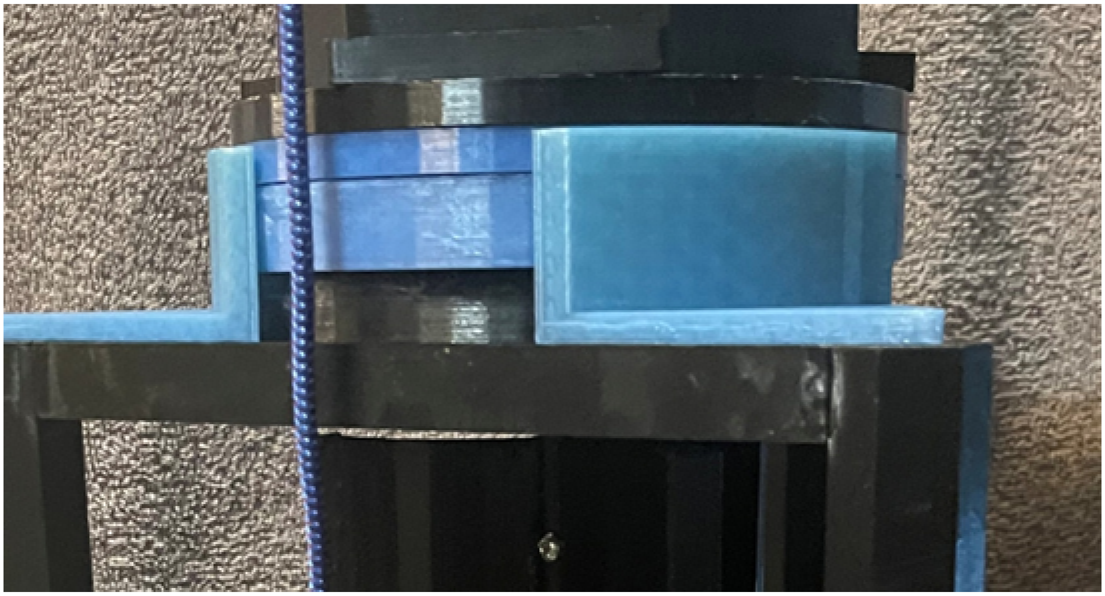

Figure 5: Photo of assembled gearbox mounted in frame

Testing revealed that effective generator activation occurred at wind speeds of approximately 20 mph or greater, rather than the lower 5 mph target. While the planetary configuration successfully demonstrated structural feasibility and compactness, friction losses limited its low-speed efficiency. Future iterations of the gearbox could benefit from improved materials, tighter manufacturing tolerances, and lubrication strategies to reduce internal resistance and enable earlier generator startup.

5.2.2. Electrical Housing

The electrical housing of the Portable Wind Power Charger is positioned at the top of the frame (see Figure 2 and 6) and serves as the protective enclosure for the generator and power regulation components. This housing was designed to meet several practical criteria including weather resistance, ease of access for field maintenance, and protection from environmental debris. Its placement above the turbine shaft minimizes the risk of water ingress and allows for gravity-assisted cable management during system operation.

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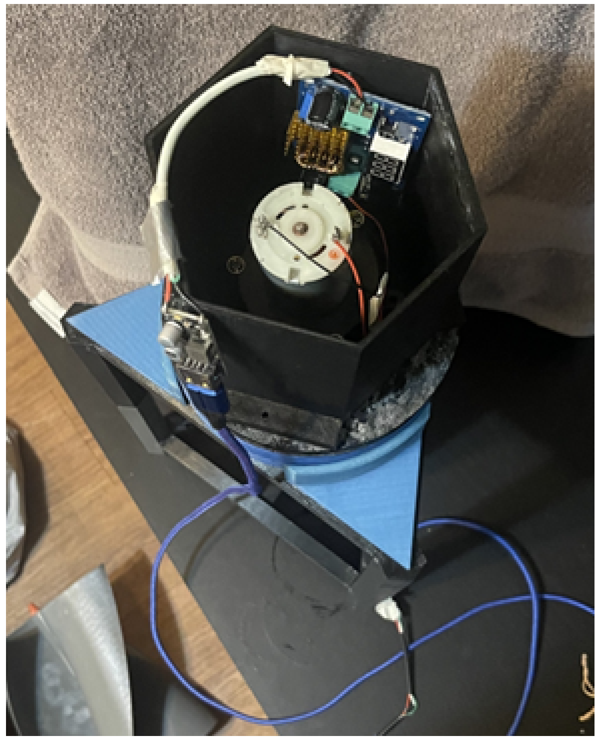

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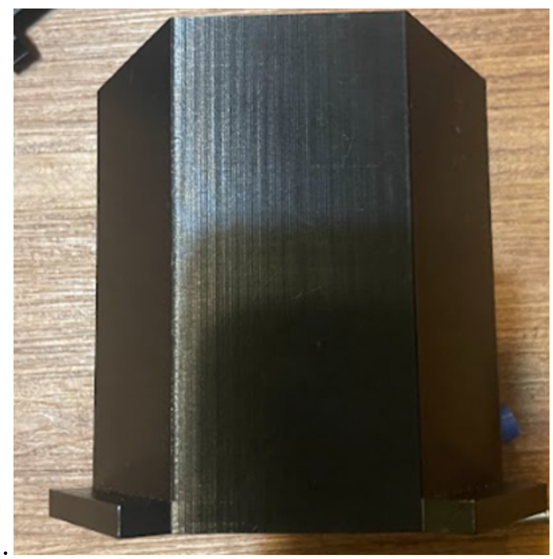

Figure 6: 1. Electrical box-mounted electrical housing in the fully assembled structure 2. Chowing the top view of the electrical box, 3. Side view of the electrical box.

The enclosure was 3D printed using PLA and includes integrated mounts for securing the boost and buck converter modules. To reduce the risk of accidental short circuits or heat buildup, the converters were mounted using thermal adhesive pads that allowed for passive heat dissipation across the housing shell. The housing also includes aUSB-C output port that provides regulated 5V power to external devices. Although initially envisioned to support sensor integration and live system monitoring, those features were ultimately excluded in the final prototype. The housing design, however, remains modular and accessible for future expansion.

5.2.3. Frame

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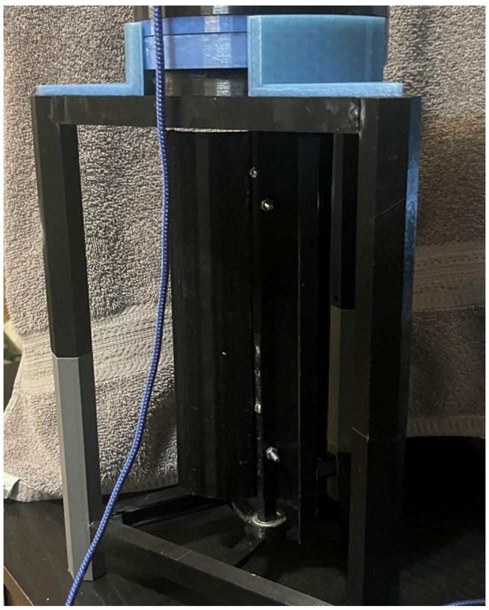

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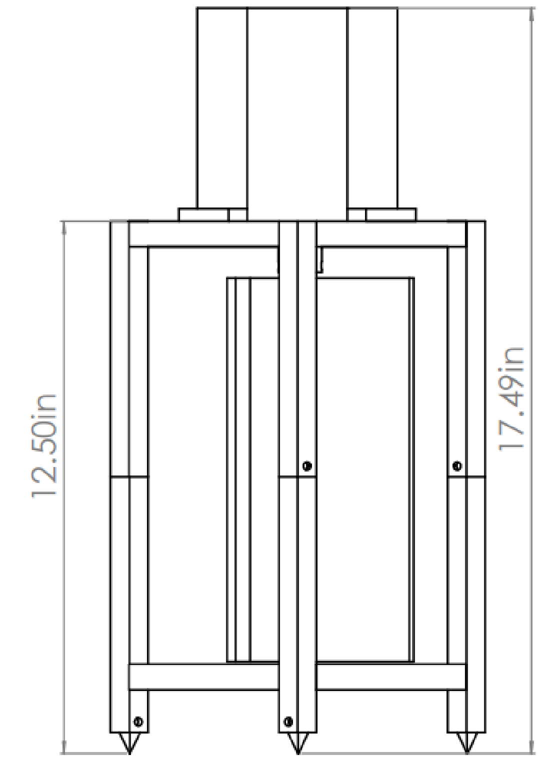

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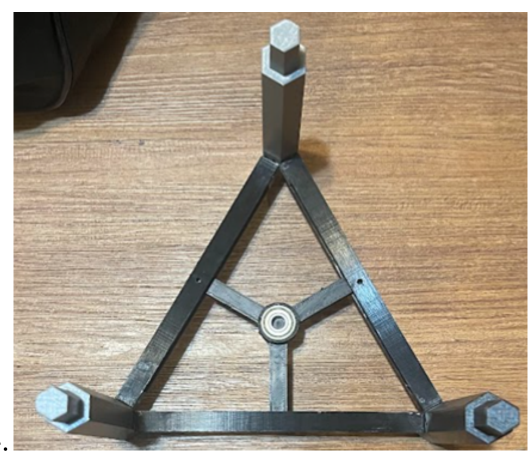

Figure 7: 1. Real picture of frame with square blades, 2. Dimensions of the complete frame with hooks, 3. Disassemble the top part of the frame. 4. Disassemble the bottom part of the frame.

The frame of the Portable Wind Power Charger forms the structural foundation that supports all other subsystems during operation. It was designed for rapid assembly, lightweight transport, and stable performance in varied outdoor conditions. The entire frame is constructed from 3D-printed PLA components that snap together using press-fit joints, eliminating the need for specialized tools or fasteners during setup in mild to moderate weather conditions. This modularity allows the system to be assembled in under ten minutes and disassembled just as quickly for compact storage and transport.

The structural layout consists of a triangular base ring into which three vertical legs are inserted (see Figure 7.4). Each leg features a hooked terminal compatible with standard tent stakes, which are used to anchor the system securely into the ground. The legs are angled outward to increase the footprint and reduce the likelihood of tipping under wind gusts. The stability of this tripod configuration was confirmed during field testing, where the system remained upright in wind conditions reaching up to 30-40 mph.

The central shaft supporting the turbine runs vertically through the midsection of the frame, passing through the planetary gearbox and connecting to the generator at the top. The frame's geometry ensures that the shaft remains aligned regardless of terrain slope or ground irregularities, maintaining efficient rotational transfer. While the structure is made entirely from PLA for the prototype, it was designed with enough tolerance and wall thickness to endure repeated assembly cycles and outdoor exposure. Optional screw holes were included in high-load areas of the legs and hubs to allow for reinforcement with mechanical fasteners if needed in future use.

When disassembled, the entire frame fits into a packed volume of approximately 7.56 liters and contributes to a total system weight of only three pounds. This compactness and low weight confirm the frame's effectiveness in meeting portability requirements while maintaining mechanical integrity under real-world conditions.

5.3. Turbines

The turbine subsystem of the Portable Wind Power Charger is responsible for converting wind energy into rotational mechanical energy, which is then transmitted through the gearbox to the generator. The turbine was designed with modularity and environmental adaptability in mind, allowing for the rapid swapping of blades and enabling performance optimization across different wind conditions. The modular hub and blade interface support quick assembly and field customization.

5.3.1. Blade Design and Performance

Two blade designs were developed and tested during the project: a flat square blade and a curved blade. The square blades (see Figure 8.1) were initially selected for their ease of fabrication and potential to generate high torque under strong wind conditions. However, during testing, they demonstrated high startup drag, which significantly limited their ability to begin rotation under low-wind scenarios.

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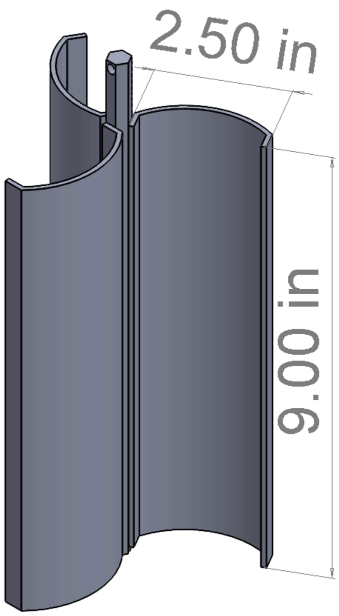
5. 

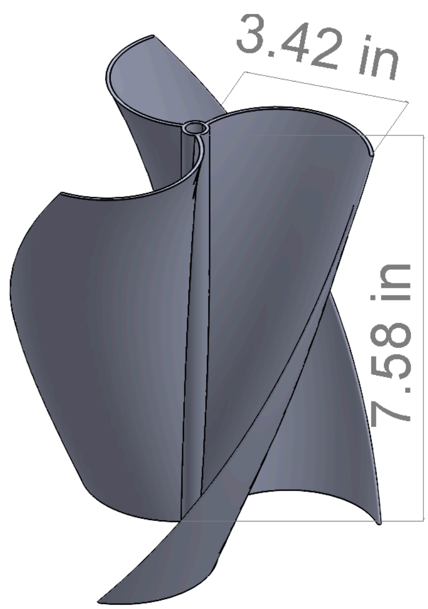
6. 

Figure 8: Side-by-side comparison of square (Left) vs. curved (right) blades. 1.and 2. Side view of blades. 3. and 4. Top view of blades. 5. And 6. Dimensions of blades.

In contrast, the curved blades (see Figure 8.2) were shaped with a smooth arc and consistent twist to improve airflow and reduce resistance during rotation. These blades were also printed in PLA and demonstrated significantly better startup characteristics during simulation and field tests. The curved blades exhibited a lower drag profile and began spinning more consistently across a broader range of wind speeds.

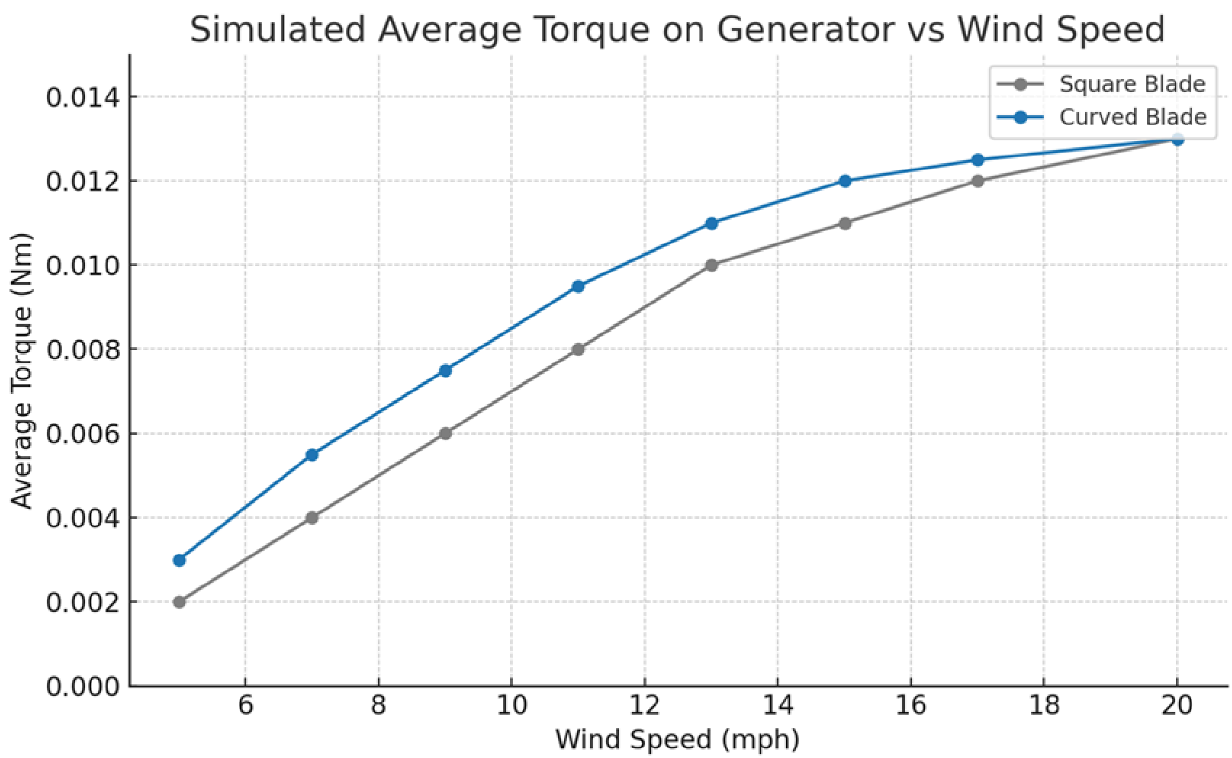


Figure 9: SolidWorks simulation results or torque vs. wind speed chart comparing square and curved blade performance.

Despite the improved performance, blade startup in the final configuration still required wind speeds of approximately 20 mph or greater. While this was higher than the original design target, the curved blades consistently outperformed the square variant under both steady and gusting wind conditions. In a five-minute test at 20 mph, the curved blades generated approximately 0.104 Wh, compared to 0.0521 Wh from the square blades. These results confirmed the effectiveness of the curved profile for increasing rotational responsiveness and maintaining continuous generation once motion had begun.

5.3.2. Blade Mounting and Hub System

To support rapid field changes and testing, both blade types were made interchangeable through a central turbine hub. This hub was designed with six equally spaced bolt-in slots, allowing for either three- or six-blade configurations depending on environmental needs. During testing, three-blade setups showed lower inertia and improved startup at marginal wind conditions, while six-blade arrangements provided smoother operation at higher wind speeds.

Figure 10: Photograph of the shaft connection.

The hub connects directly to the shaft (See Figure 10) of the planetary gearbox using a hexagonal press-fit interface with added friction collar support to prevent slippage. Balancing tabs were incorporated to reduce wobble during rotation and improve energy transfer consistency. Field results confirmed that the modular hub system functioned reliably and could be adapted quickly without specialized tools.

5.4. Electrical

The electrical subsystem of the Portable Wind Power Charger converts rotational mechanical energy from the turbine into regulated DC electrical output suitable for charging small devices. The system (see Figure 11) uses a compact DC generator paired with a two-stage voltage regulation circuit consisting of a boost converter followed by a buck converter. This configuration steps up and stabilizes the fluctuating output from the generator, ultimately delivering a clean 5V output through a USB-C port. The electrical components are housed in the top-mounted enclosure to protect them from environmental exposure and to centralize the system's power interface.

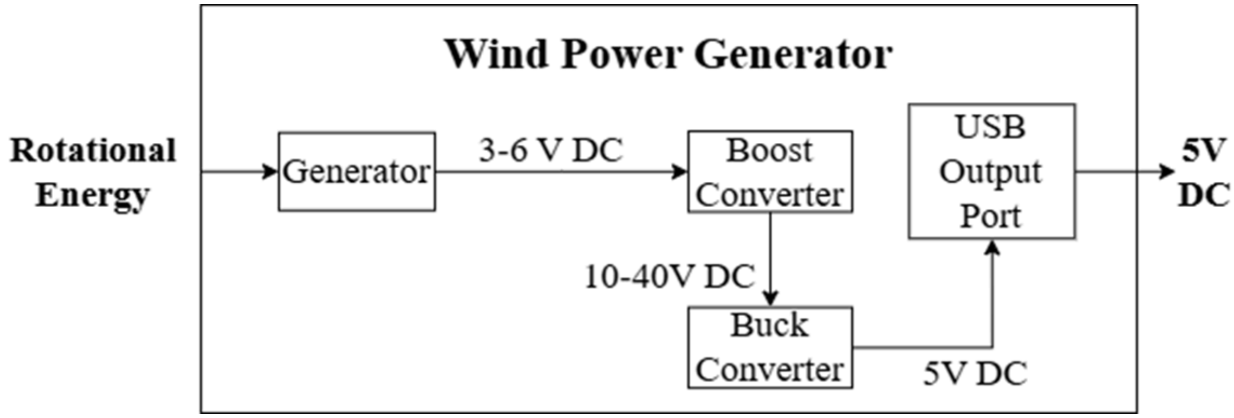


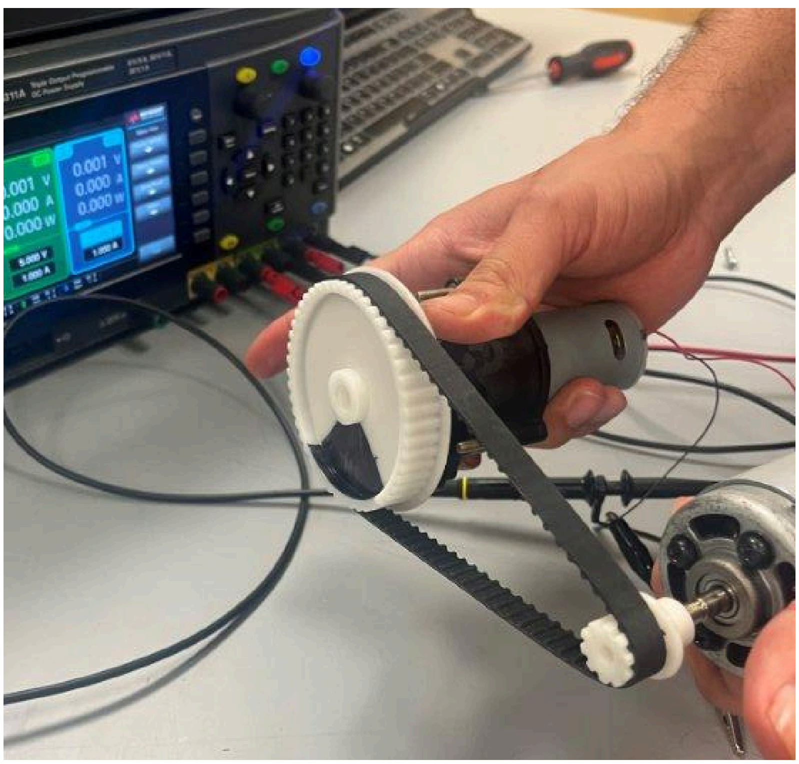
Figure 11: Electrical Schematic.

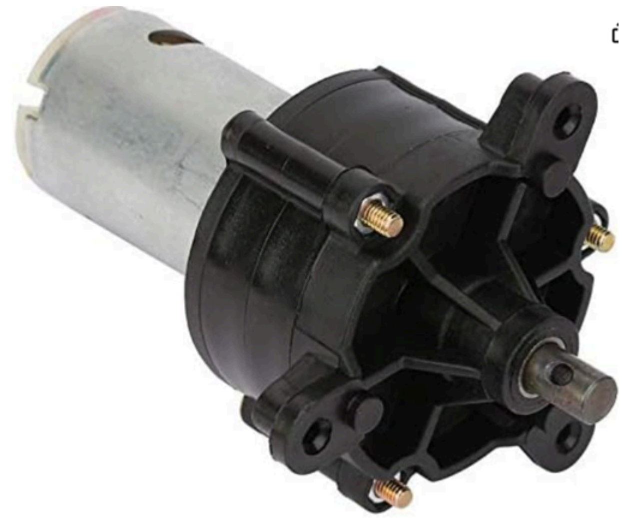
5.4.1. Generator Selection and Performance

The generator selected and integrated into the PWPC is a compact DC generator. This component was chosen due to its compatibility with the turbine assembly, particularly its ability to begin generating electrical output at low rotational speeds, which aligned with the mechanical output of the selected gearbox and blade configuration. Additionally, because our desired output was a DC signal, this type of generator eliminated the need for an AC to DC rectifier. The commutator inside the generator acts as a rectifier which allows the generator to output a DC signal. This would remove a component from our final design and reduce the complexity of our system. The generator was installed within the upper structure of the system, and its performance was verified during bench testing phases.

As reported earlier in this project, the measured startup torque for the generator was determined to be 0.0068 Nm. This value was experimentally recorded using a torque test rig that applied measured rotational force to the generator shaft. The torque value directly influenced the design of the turbine blade and the transmission gearing, ensuring that the system could begin producing power under realistic, low-wind environmental conditions.

To define our generator's characteristics, voltage output from the generator was recorded across a range of test speeds under no load. The generator was driven using a motor salvaged from an old electric leaf blower and connected together by a belt and gear system as shown in Figure 12. By powering the salvaged motor with a DC power supply and varying the voltage, the rotational speed of the generator could also be varied. Testing started at an input voltage of 2V, increasing in increments of 0.5V and testing concluded once an input voltage of 10V was achieved. At every increment, the generator's rotational speed was measured using a stroboscope and the output voltage was measured using an oscilloscope. The generator produced voltages ranging from 0V to approximately 17VDC depending on RPM, which can be seen in Figure 13. It was found that voltage output increased linearly with increased generator rotational speed within the range of speeds tested. Notably, around 130 RPM, the generator was observed to produce approximately 3V. This is an important output voltage for the generator as it is the minimum required voltage for our boost converter. Due to this fact, a generator speed of 130 RPM would become the minimum required operating speed. These findings confirmed the generator's suitability for variable wind energy input.

1. 



2.

Figure 12: 1. Test setup for the generator characteristics test. 2. DC generator used for the project.

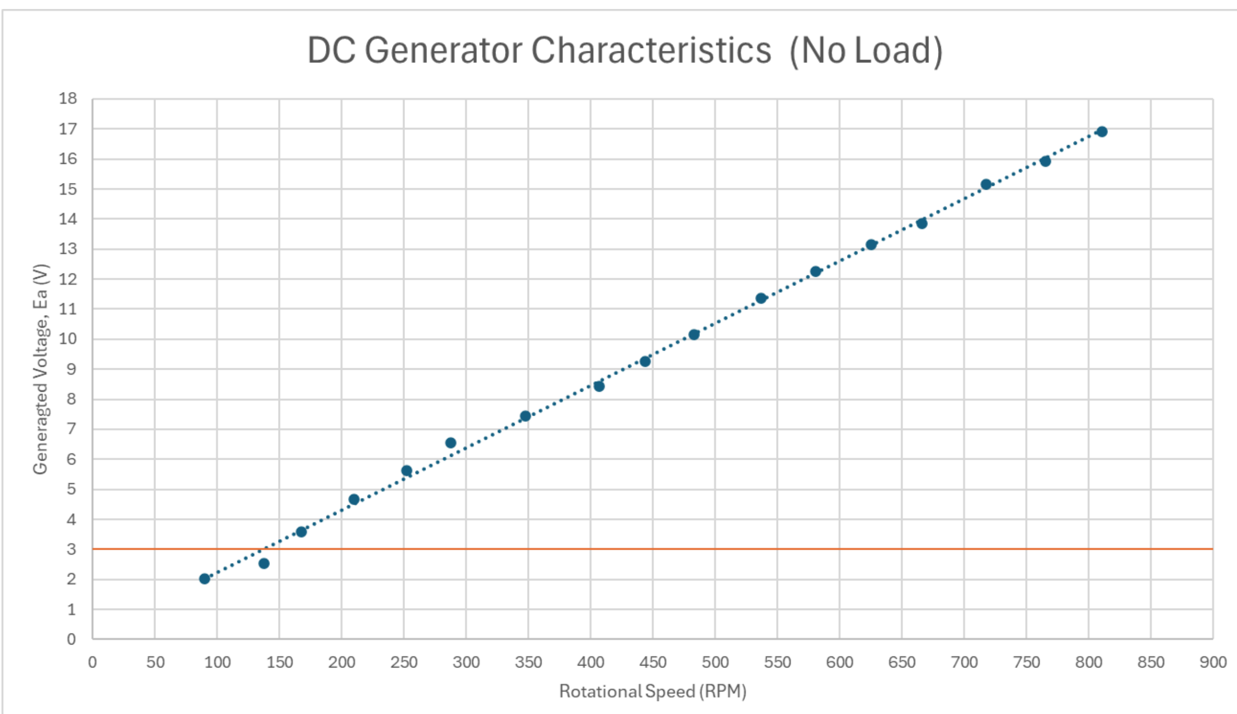


Figure 13: Generator voltage output vs. RPM

5.4.2. Boost Converter

The first stage of voltage regulation in the Portable Wind Power Charger is performed by a compact, adjustable DC-DC boost converter shown in Figure 14. This module was selected based on its wide input voltage range (3V to 35V) and its ability to reliably elevate the generator's variable output voltage to levels suitable for subsequent regulation. It plays a critical role in stabilizing energy flow during inconsistent or fluctuating wind conditions by maintaining an output above the minimum threshold required by the downstream buck converter.

The boost converter was configured to output a voltage slightly above 5V, typically in the 5.5V to 6.0V range, depending on the input conditions. This ensured that even with slight dips in generator output during wind variation, there would be adequate voltage headroom for the buck converter to maintain a clean and constant 5.0V USB-C output. During field operation, input voltages to the boost converter ranged from 3V at low RPMs to over 10V during strong wind events, demonstrating the generator's full dynamic range.

Thermal performance was a key consideration during integration. Despite compact enclosure dimensions, the converter operated within acceptable thermal limits during all testing phases, aided by the relatively short bursts of continuous generation caused by variable wind speeds.

Output ripple of the boost converter was mitigated through the inclusion of capacitors positioned at the output terminals of the boost converter as shown in Figure 15.. This filtering helped smooth voltage fluctuations introduced by both wind inconsistency and internal switching noise. During testing, ripple was observed to decrease significantly after filtering, with the resulting voltage remaining within 0.2V of the target setpoint in most conditions. Although not sufficient for highly sensitive electronics, this regulation level was acceptable for USB power delivery.

The performance of the boost converter was validated in both bench and field conditions, where it demonstrated reliable behavior across a wide range of input voltages. Combined with the buck converter in the subsequent stage, it formed the core of a two-stage regulation system capable of maintaining user-ready 5V power delivery from inconsistent wind input.

Field tests demonstrated that even during wind shifts, the USB-C port maintained an output voltage between 4.8V and 5.0V, with sufficient current to charge standard devices. The converter modules were mounted directly inside the electrical housing using thermal adhesive pads to aid passive heat dissipation.

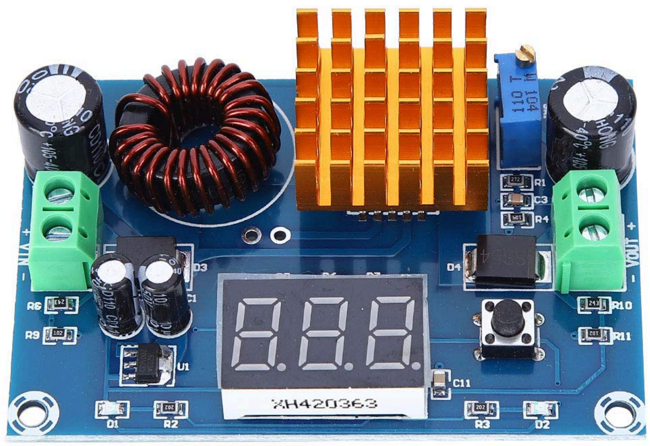


Figure 14: Boost converter used showing Vin at the left and Vout at the right, both with a green connector.

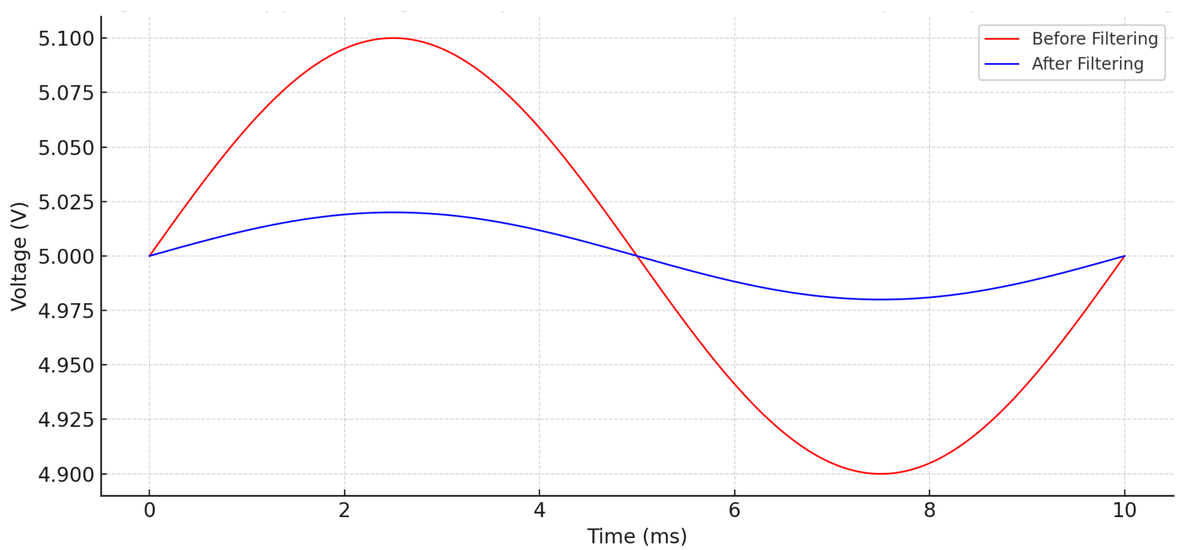


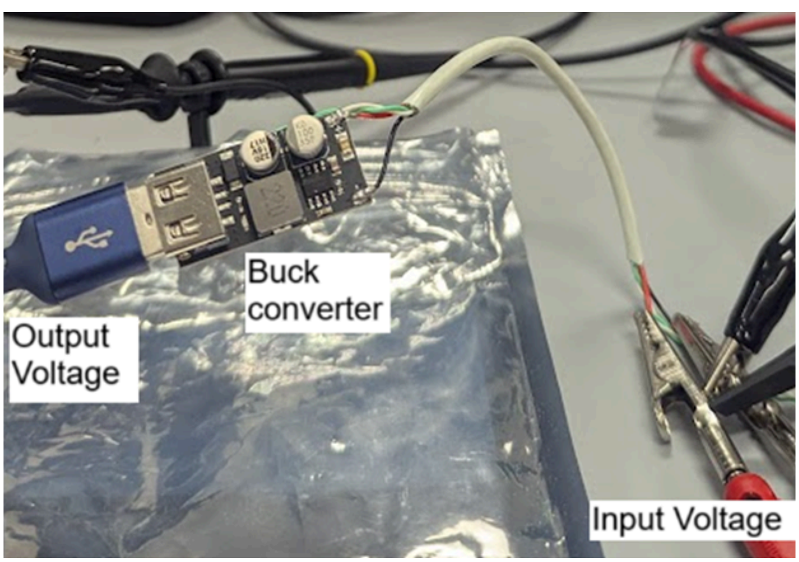
Figure 15: Ripple voltage comparison chart before and after output capacitor filtering.

5.4.3. USB Output and Safety Features

The final stage of the electrical subsystem in the Portable Wind Power Charger uses a buck converter to stabilize the elevated voltage from the boost stage and deliver a consistent 5.0V output through a USB-C port. This stage ensures that the voltage delivered to user devices remains within safe and reliable charging limits, regardless of upstream fluctuations in generator speed or wind variability.

The buck converter, a DROK USB-compatible DC-DC module (see Figure 16), was selected for its ability to maintain tight output voltage regulation with moderate thermal footprint. It was configured to accept input voltages ranging from approximately 5.5V to 12V, ensuring it could handle the output of the boost converter even during strong wind surges. The converter's output was fixed at 5.0V ±0.2V through onboard trimmer calibration, which was verified during load testing with both resistive and USB-connected devices.

The USB-C output port was integrated directly into the top-mounted electrical housing. To increase system resilience, the output path included a polyfuse and Zener diode protection circuit. The polyfuse provided automatic resettable overcurrent protection, while the Zener diode safeguarded against transient voltage spikes that could result from irregular wind conditions or user connection errors. This design was aimed at maintaining system stability while protecting user equipment from damage.

1. 


2.

Figure 16: 1. Testing setup for buck converter. 2. Close-up image of USB-C output port.

Overall, the buck converter and USB-C output system formed a robust final step in the power chain, ensuring that users could reliably draw 5V power from a naturally variable energy source. While the upstream components dictated when generation occurred, this final regulation stage guaranteed compatibility and safety for field use.

5.5. Decision Making

The final design of the Portable Wind Power Charger was shaped by a series of iterative decisions grounded in testing results, design constraints, environmental requirements, and practical considerations related to fabrication and usability. Early in the development process, multiple configurations were evaluated before converging on the current structure, mechanical layout, and electrical components. This section outlines the reasoning behind key design selections that influenced the project's overall performance and field reliability.

The initial concept featured a vertically oriented generator mounted at the base of the system with upward-facing helicoidal blades, resembling a vertical-axis wind turbine (VAWT). This configuration offered the theoretical advantage of omnidirectional wind capture and reduced structural complexity due to ground-level generator placement. However, simulations and early prototype tests revealed significant efficiency drawbacks. VAWTs typically suffer from reduced performance due to unfavorable blade orientation throughout the rotation cycle and often require external startup assistance in low-wind conditions [32], [33]. Based on these findings, the design transitioned to a horizontal-axis layout with top-mounted generator and downward-facing blades, which offered superior startup behavior, better structural balance, and easier access to sensitive components [30], [31].

The selection of the planetary gear system was driven by the need to amplify low-speed turbine rotation into generator-compatible shaft speeds. Planetary gear trains were chosen over traditional spur gear systems due to their compact, concentric design and ability to distribute torque evenly [36]. The three-stage tiered arrangement was developed to multiply rotational speed within a confined space. Although material friction and print tolerances introduced mechanical losses, the planetary system remained structurally sound and demonstrated scalable potential for future refinement.

Blade geometry was another critical area of exploration. Flat square blades were fabricated first due to their ease of design and high torque potential at strong wind speeds. However, testing revealed that their high drag significantly delayed startup. To address this limitation, a second set of curved blades was designed using aerodynamic principles inspired by Darrieus rotor profiles [14], [34]. These blades offered smoother rotation and lower drag, resulting in faster startup and greater power consistency. Based on comparative testing, the curved blades were selected as the standard configuration for field deployment.

In the electrical subsystem, component decisions were governed by compatibility with variable input voltage and the need for USB-standard output. The two-stage boost and buck converter system was selected after bench testing confirmed it could reliably regulate generator output across changing wind speeds. Simpler one-stage converters were initially considered but failed to provide consistent voltage stability during gusts and partial startup. The inclusion of basic protection circuitry—polyfuse, Zener diodes, and strain relief—was also prioritized to ensure durability and user safety during field operation [27].

Finally, the use of 3D-printed PLA components across the structure, gearbox, and blade assemblies was a deliberate decision based on accessibility and rapid prototyping needs. While not optimal for long-term mechanical durability, PLA enabled cost-effective iteration throughout the semester and allowed the team to test multiple revisions without delay. Each component was evaluated based on print tolerance, assembly fit, and its contribution to system integrity under real-world conditions.

These decisions reflect a continuous tradeoff between ideal performance, real-world limitations, and rapid development constraints. The final design represents a balance of these factors and serves as a baseline for future improvement through higher-grade materials, tighter tolerances, and expanded power management features.

5.6. Power Budget

The power budget for the Portable Wind Power Charger was established to determine whether the system could meet its goal of reliably powering small electronic devices under off-grid conditions. The design objective was to deliver between 6 to 10 watt-hours of usable energy over a 4–5 hour operating period. This range was selected based on the average energy consumption of modern smartphones, GPS units, and rechargeable LED lighting used in outdoor or emergency settings.

Power generation began at wind speeds of approximately 20 mph due to frictional limitations in the gearbox. Under these conditions, testing with the curved blades showed output voltages stabilized between 4.8V and 5.0V through the USB-C port. Real-time charging was confirmed with a variety of resistive loads and USB-powered devices. During field trials, a 5-minute test with the curved blades at 20 mph produced approximately 0.104 watt-hours of energy, while the square blades yielded 0.0521 watt-hours in the same timeframe. These results were extrapolated to predict that the system, when continuously exposed to strong wind conditions, could generate up to 1.2 watt-hours per hour using the curved blade configuration.

The output was regulated by a two-stage DC-DC conversion process, consisting of a boost converter that elevated the raw generator voltage followed by a buck converter that stabilized the final output at 5V. The combined efficiency of the conversion system was estimated to be approximately 75–85%, accounting for voltage ripple, switching losses, and cable resistance. Assuming consistent wind conditions at or above the activation threshold, the system was expected to provide a continuous output of roughly 1 to 1.5 watts, making it sufficient for emergency recharging applications over several hours of exposure.

Internal power losses were accounted for by estimating the efficiency drop across each subsystem. Mechanical losses from drivetrain friction, electrical losses in conversion stages, and minor standby drain from voltage regulation circuits contributed to a total system efficiency slightly below initial expectations. Nevertheless, the energy budget confirmed that the system could deliver functional power output suitable for field applications, particularly when paired with energy-aware user behavior and intermittent hand-crank input during low-wind periods.

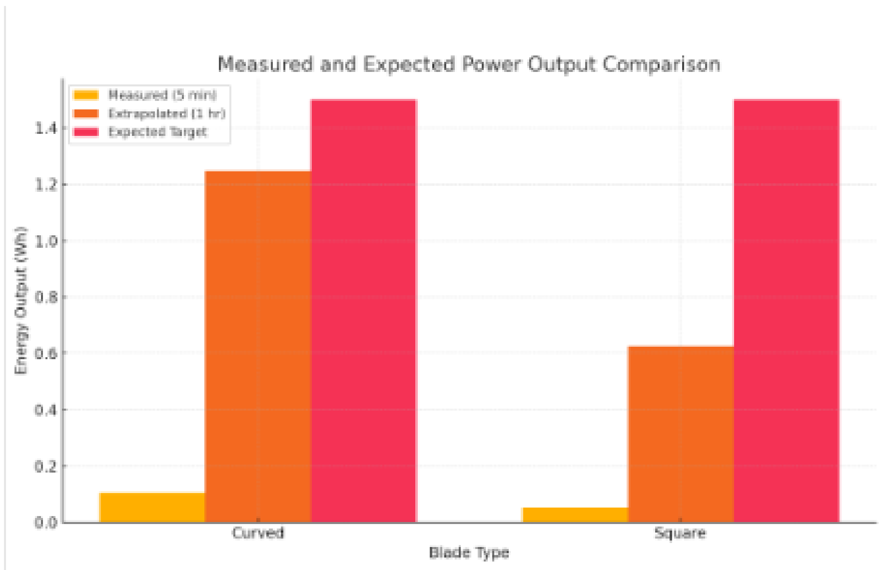


Figure 17: Comparison of Blade Performance Against Expected Energy Output Targets.

6. Project Planning

The development of the Portable Wind Power Charger followed a structured timeline that moved from initial research and conceptualization to physical testing and final presentation. Planning began in October with a focus on identifying user needs, reviewing existing off-grid charging technologies, and defining functional requirements for a small-scale wind energy system. During this period, the team also explored initial structural configurations and environmental constraints, which informed the earliest 3D model drafts and component estimates.

By November, work progressed toward the selection and ordering of electrical components, including the generator, power converters, and basic wiring elements. Mechanical development centered initially on the structural frame and turbine blade interface. The team created basic mock-ups and housing designs using SolidWorks while concurrently finalizing electrical schematics. These early models focused on ease of assembly and deployability, though a detailed drivetrain had not yet been finalized.

The planetary gearbox, originally not part of the planned architecture, was introduced late in the build process. In January, after testing early blade and generator configurations, the team determined that generator startup performance under low wind conditions was insufficient without additional mechanical amplification. This led to the rapid design, modeling, and fabrication of a tiered planetary gear system, which was printed and integrated just before full system testing began. Due to time constraints, gear optimization and surface finishing were limited, and the printed gears exhibited internal friction that impacted startup thresholds.

Throughout February and March, the team conducted iterative testing to evaluate blade performance, structural stability, and voltage output. The curved blade design was refined based on wind tunnel and outdoor data, and the USB-C output system was validated through resistive load tests. The team met regularly to review testing results, troubleshoot issues, and document system revisions. April was focused on finalizing adjustments, compiling the technical report, and preparing for the project’s final presentation.

6.1. Bill of material

The Portable Wind Power Charger was constructed using a focused selection of commercially available components, balancing cost, performance, and ease of integration. A detailed bill of materials (BOM) is provided below, outlining the parts used, their respective quantities, and associated costs. All pricing was based on actual purchase costs at the time of development and is accurate to the components documented throughout the project.

The core energy generation component, a DC Miniature Hand Cranked Generator, was purchased for $22.53. This was paired with two voltage regulation modules: a DC-DC Boost Converter (XH-M411 model), used to stabilize generator output at low voltages, priced at $8.48, and a DROK USB Buck Converter, used to further condition the voltage for regulated 5V DC output, priced at $12.99. For structural components, a full spool of PLA filament used to print the turbine frame and housing cost $20.00. Mechanical assembly was completed using 32 stainless steel screws and nuts at a cost of $16.00. To ensure environmental protection, a 4.4 oz container of general-purpose sealant was applied throughout the enclosure and connections, totaling $37.40. Finally, a rollerblade bearing, used in the generator shaft alignment, was sourced for $1.00.

The total cost of the project components came to **$118.40,** as detailed in table 2, representing a low-cost solution for off-grid power generation with regulated DC output suitable for small electronic devices.

Item Name	Number	Price
DC Miniature Hand Cranked Generator	1	$22.53
DROK USB Buck Converter	1	$12.99
DC-DC Boost Converter	1	$8.48

PLA Filament (Printed Components)	1 spool	$20.00
Stainless Steel Screws/ and nuts	32	$16.00
General-Purpose Sealant	4.4 oz	$37.40
Rollerblade Bearing	1	$1.00
TOTAL	7	$118.40

Table 2. Bill of materials

6.2. Timeline

The project progressed into its critical building phase after completing two months of research and preparation in October and November. December was dedicated to refining detailed designs, running simulations, selecting materials, and ensuring all components were ready for prototype assembly. In January, the team constructed the prototype, integrated its key subsystems, and conducted initial testing to verify functionality. February focused on field testing the prototype in real-world conditions, gathering feedback on performance, durability, and usability, which informed design refinements.

During March, the refined prototype underwent advanced testing and stress evaluations to ensure long-term reliability, and detailed documentation, including drawings and diagrams, was completed. Finally, in April, the project concluded with final adjustments, the preparation of technical reports, and a formal presentation and demonstration of the generator to stakeholders. A full timeline with milestones was included in Appendix C to ensure all tasks were tracked and executed effectively.

N. Task	October	Duration weeks
1	Project Kick-Off	
2	Background Research and Conceptualization (Second to Fourth Week)	2
3	Preliminary System Design (Third and Fourth Week)	2
	November	
4	Detailed Electric Schematic and Component Selection (First to Third Week)	3
5	Parts Procurement (Third and Fourth Week)	1
6	Finalize Conceptual Design and Environmental Compliance (Fourth Week)	1
	December	
7	Design and Simulation (Entire Month)	4
8	Material Selection (Third and Fourth Week)	2
9	Prototype Component Sourcing (Fourth Week)	4
	January	
10	Prototype Assembly (First to Third Week)	3
11	Initial Testing and Calibration (Fourth Week)	1
	February	
12	Field Testing and Feedback (Entire Month)	4
13	Analysis and Redesign (Third and Fourth Week)	2
14	Detailed Drawings (Throughout the Month)	4
	March	
15	Prototype Refinement (Entire Month)	4
16	Advanced Testing (Third and Fourth Week)	2
	April	
17	Final Adjustments and Documentation (First to Second Week)	2
18	Project Wrap-Up (Third Week)	1
19	Preparation for Presentation (April 15)	2

Table 3. Schedule of the Project.

6.3. Teamwork Breakdown

Throughout the duration of the project, the team was composed of three members: Josiah, Miguel, and Zane. Responsibilities were distributed based on each member's area of focus and skill set. Josiah was responsible for the mechanical design of the project, including the structural frame, gear system, and the individual components needed for assembly. Miguel managed the 3D printing of all designed parts and maintained comprehensive documentation of all design changes, decisions, and team discussions. Zane took the lead in evaluating the electrical performance of the DC generator, conducting tests to determine its output characteristics under various conditions.

While individual roles were defined, all three team members collaborated on wind-based testing of the generator. This involved assembling different design configurations, gathering data, and evaluating performance to ensure the system met functional requirements.

The team held regular in-person meetings every Friday to coordinate progress, address challenges, and conduct hands-on work. These sessions were complemented by ongoing digital communication to share updates, ask questions, and confirm decisions. However, communication efficiency was sometimes a challenge. One team member had consistent difficulty arriving on time to group meetings, and response times to messages could be significantly delayed, occasionally hindering workflow and slowing overall progress. This was handled with understanding, but it did present obstacles in maintaining momentum during critical stages.

Conflicts or disagreements were generally addressed through open discussion. Team members were encouraged to present their viewpoints with supporting rationale. Resolution typically came either when one member's argument was backed by sufficient technical justification that convinced the others or through a majority consensus, with two members in agreement and one in opposition. While not always smooth, this method ensured that decisions were made based on merit and collaborative judgment.

7. Project Results

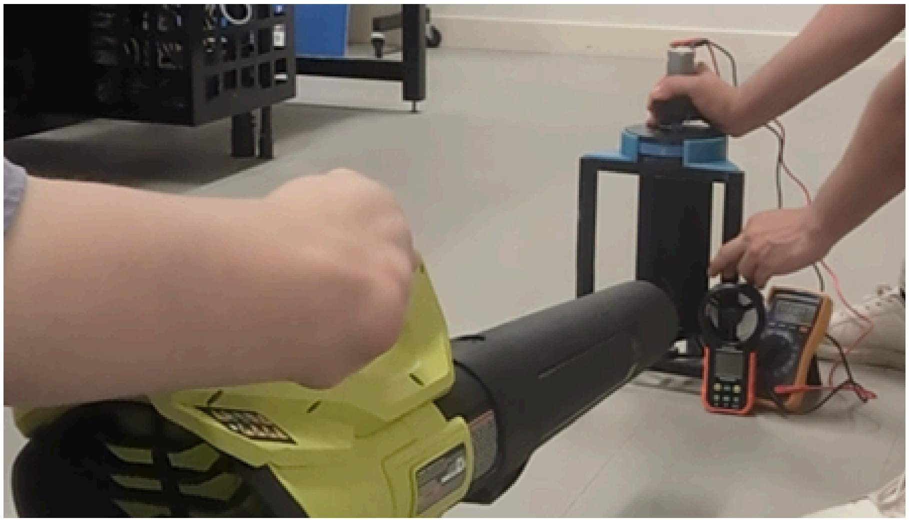
The performance evaluation of the Portable Wind Power Charger was conducted through a series of structured field tests designed to analyze its mechanical and electrical behavior under realistic wind conditions. Performance data was gathered under controlled and repeatable conditions using a combination of natural outdoor wind and a high-powered wind blower to simulate consistent wind speeds. This setup allowed for a uniform test environment across multiple structural configurations and blade geometries.

To quantify turbine responsiveness and rotational dynamics, an accelerometer was near the turbine hub during all tests. Wind speed was measured using a handheld anemometer placed at the turbine height, and voltage output was logged using a multimeter or oscilloscope. These instruments provided synchronized mechanical and electrical data, enabling a clear understanding of how different system configurations affected energy performance.

Three distinct mechanical configurations were tested, each defined by a different number of support tiers: a two-tier system (see Figure 3), a one-tier system (see Figure 4), and a no-tier system (see Figure 22.1). In this context, a "tier" refers to the number of planetary gear system extensions placed between the turbine base and the turbine blades. Each tier added height to the turbine's position above ground level and increased the vertical distance between the turbine blades and the generator mount. The two-tier configuration provided the maximum gear aid, while the one-tier configuration halved this, and the no-tier configuration mounted the blades directly. These structural variations were intended to evaluate how turbine, mechanical leverage, and airflow exposure impacted startup and power output performance.

Each structural configuration was tested using both square and curved turbine blades to isolate the effect of blade shape on energy harvesting efficiency. For every test run, a wind blower was positioned at a distance to deliver consistent wind velocity as shown in Figure 19., while output voltage and energy accumulation were monitored under resistive loads and USB charging conditions. Tests were conducted in five-minute intervals and repeated for consistency. Results were then used to compare not only energy performance, but also rotational smoothness, startup delay, and structural ease of assembly across configurations.

The following sections present a detailed analysis of each configuration tested, beginning with the full-height two-tier system.

1. 

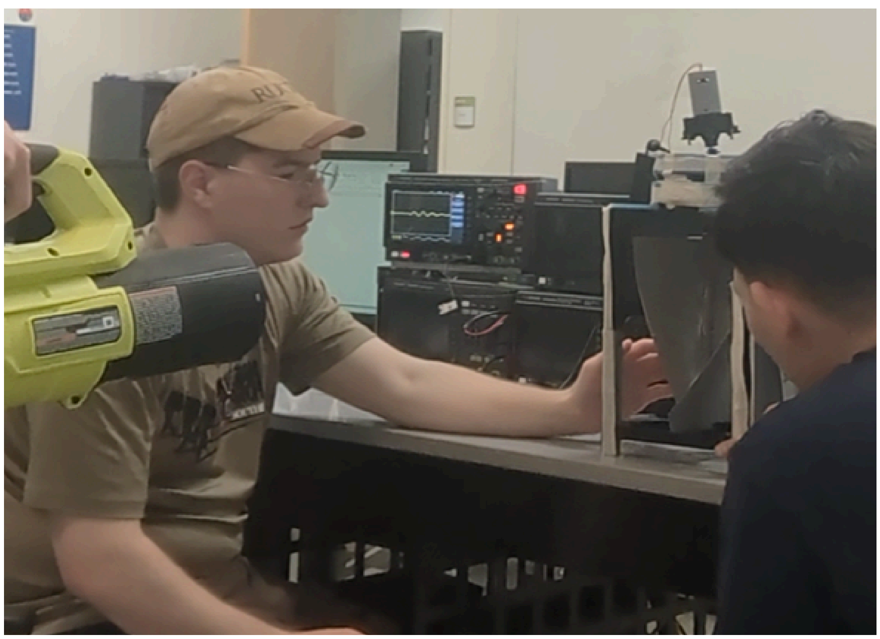
2. 

Figure 19: 1. Test configurations under blower testing with 0 tiers and square blades. 2. Test configurations under blower testing with 2 tiers and curved blades.

7.1. 2 Tier

The two-tier configuration refers to the setup that includes two stacked planetary gear stages connected between the turbine shaft and the generator. This arrangement was designed to mechanically amplify turbine rotation and overcome the generator's startup torque threshold. By cascading two identical gear assemblies in series, the rotational speed from the turbine blades was significantly increased before reaching the generator. The aim of this configuration was to assess how added mechanical amplification affects voltage output, startup responsiveness, and overall energy generation.

Testing was conducted using a high-powered wind blower to provide repeatable airflow across the turbine. A handheld anemometer was used to confirm wind speeds at approximately 20 mph up to 47–52 mph during each test. Voltage output was monitored using a multimeter while the generator was connected to a resistive load simulating typical USB-powered device conditions. Each test lasted less than five minutes and was terminated since I was not able to make it to enough voltage to provide power to output.

Curved and square blade sets were tested independently under identical conditions. The curved blades spun up faster and exhibited smoother motion at both wind speeds, while the square blades took longer to activate due to higher aerodynamic drag. Despite their slower startup, the square blades produced higher peak voltages. At 20 mph, they achieved an average of ~0.31 V, compared to ~0.215 V for the curved blades. At high wind speeds (52 mph for square, 47 mph for curved), the square blades peaked at ~0.71 V while the curved blades reached ~0.441 V.

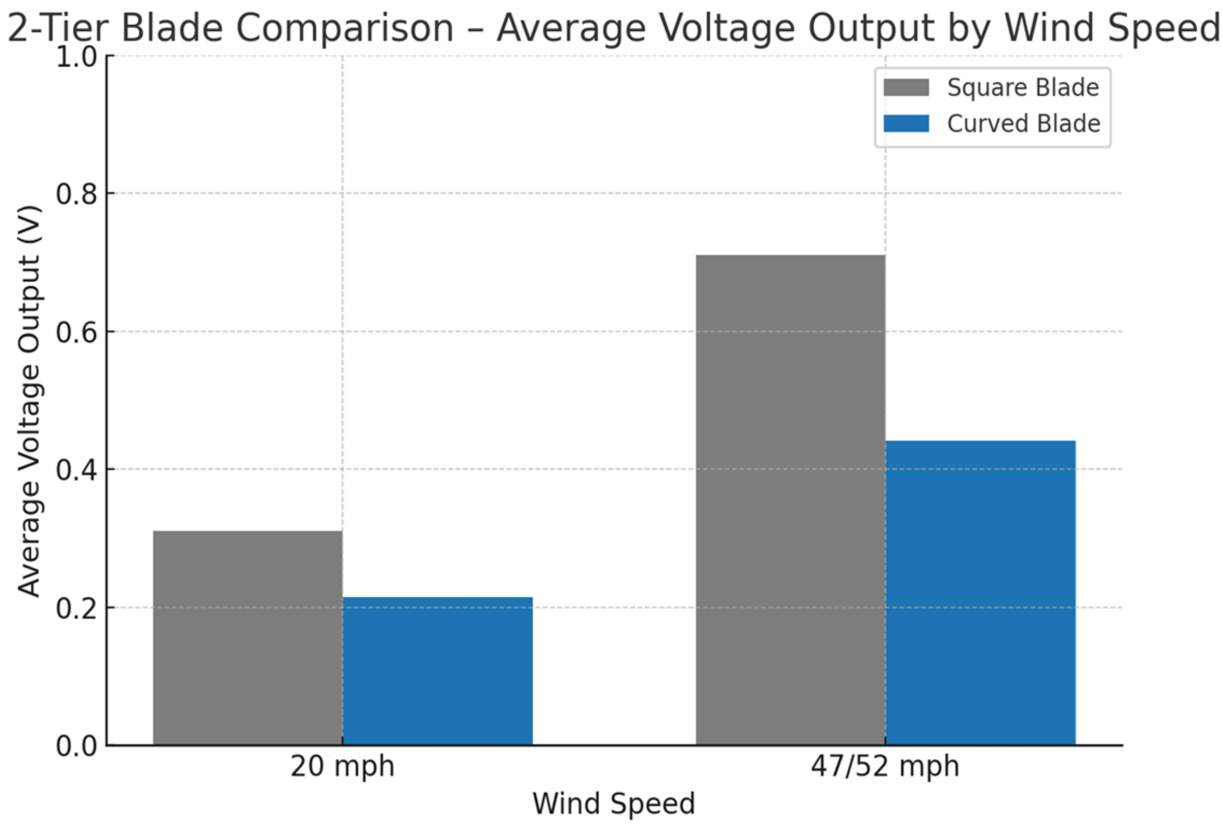


Figure 20: Average Voltage output blade comparison by wind speed with 2 tiers.

While the square blades demonstrated higher raw voltage output, the curved blades provided better low-speed activation and mechanical stability. Their smoother rotation and lower inertia made them better suited for variable-wind scenarios, particularly when system startup is a critical concern. These findings confirm the benefit of aerodynamic blade shaping in overcoming mechanical friction introduced by multi-stage gear systems. Which is built upon when conducting the 1 tier testing.

7.2. 1 Tier

The one-tier configuration of the Portable Wind Power Charger incorporated a single planetary gear stage between the turbine blades and the generator shaft. This setup provided rotational amplification while reducing internal friction compared to the two-tier configuration. The goal of this test was to assess whether a simpler drivetrain could maintain sufficient output while improving startup behavior and reducing mechanical drag. By retaining some gearing while eliminating the second stage, the system aimed to balance torque multiplication and frictional losses.

Wind speeds were supplied using a high-powered blower, with anemometer readings confirming approximately 20 mph for the main energy output test, followed by shorter trials at wind speeds ranging from 30 to 38 mph. Voltage was recorded under both unloaded and loaded conditions using a multimeter across a resistive USB-simulated load.

Both square and curved blades were tested independently using the same conditions. At 20 mph, a five-minute test revealed that the curved blade configuration delivered approximately 0.104 watt-hours of energy, identical to its performance in the two-tier configuration. Square blades again underperformed, with a delayed startup and a recorded energy output of 0.0521 watt-hours. These values reaffirmed that blade geometry—especially under reduced mechanical resistance—directly affects both spin-up behavior and energy generation over time.

At higher wind speeds, the curved blades demonstrated exceptional voltage output. As shown in the chart below, they reached ~1.29V at 30 mph under no load, ~1.19V at 33 mph while loaded, and peaked at ~3.39V at 38 mph. In contrast, square blades registered ~0.31V at 20 mph and ~0.71V at 52 mph, consistent with their trend of higher peak voltage at higher torque, but lower responsiveness at startup.

These results suggest that while square blades can perform well under strong wind and torque-heavy conditions, they struggle in moderate wind due to their higher drag and the additional resistance introduced by the gear system. Even with only one planetary stage, internal friction between printed gear teeth and shaft alignment tolerances contributed to noticeable stalling behavior during early startup, particularly when paired with square blades. The curved blades, especially in the one-tier setup, offered a more balanced performance—overcoming friction earlier, maintaining rotational smoothness, and delivering more stable voltage output across tests. The one-tier system ultimately proved to be the best compromise between mechanical advantage and reduced internal resistance.

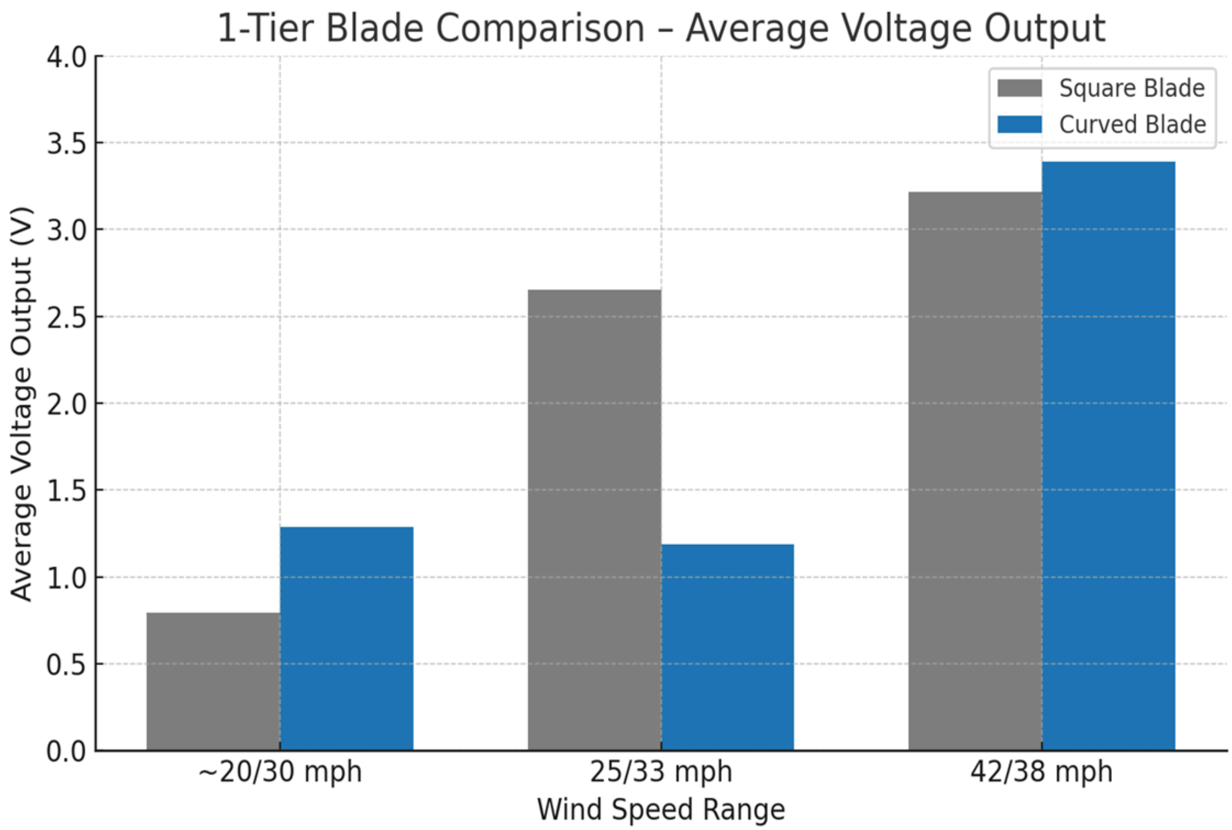


Figure 21: Average Voltage Output blade comparison by wind speed with 1 tier.

7.3. No Tier

The no-tier configuration removed all gearing mechanisms, with turbine blades mounted directly onto the generator shaft in a true direct-drive setup. This configuration represented the most mechanically efficient version of the system, with zero drivetrain friction. The goal was to evaluate how blade geometry alone influenced startup behavior and voltage output, and to determine whether the system could perform in real-world low-wind or obstructed environments without any gear amplification.

Testing was conducted using a wind blower with speeds measured at 30–40 mph. As with previous tests, voltage output was monitored using a multimeter, and rotational performance was assessed qualitatively based on startup delay, smoothness, and voltage ramp behavior. Due to the absence of gearing, the generator required significantly more input RPM to achieve usable output, as there was no mechanical multiplication to boost shaft speed.

Despite this, the curved blades achieved superior performance in both startup response and average voltage output. At just 30 mph, the curved blades generated approximately 2.9V, while the square blades, even at 40 mph, produced only around 1.1V. This result is visualized in the chart below. Unfortunately, voltage levels in both cases remained below the stable USB regulation threshold for extended periods, preventing successful completion of a 5-minute energy output test. The system was unable to maintain the voltage needed to sustain charging under load.

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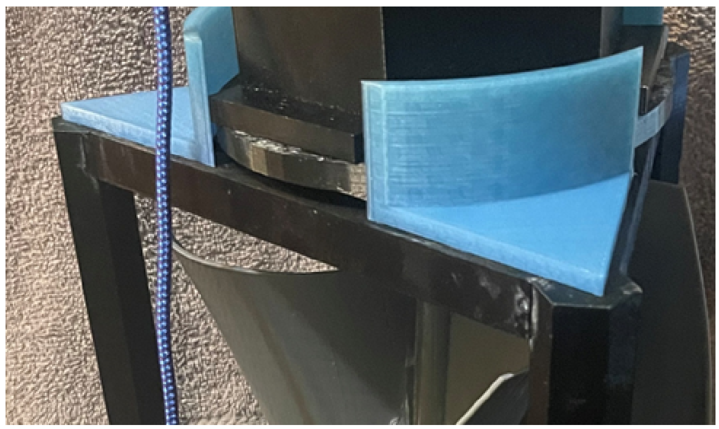

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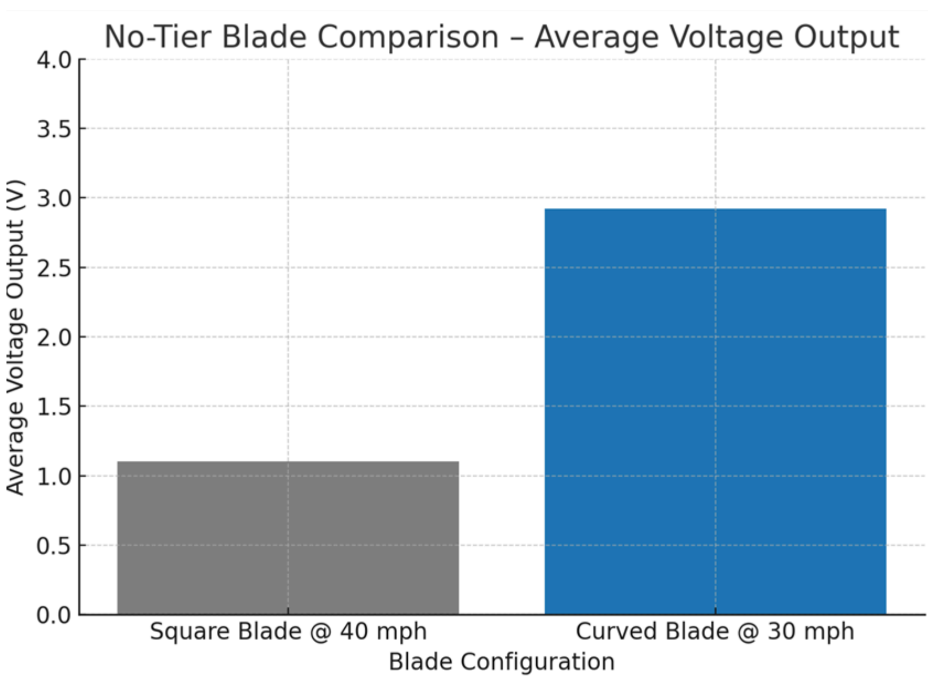

Figure 22: 1. No tier system. 2. Average Voltage output blade comparison by wind speed with 0 tiers.

These findings support the conclusion that curved blades are significantly more efficient in low-friction systems and are better suited for use in variable or obstructed wind conditions. Their aerodynamic shape allows them to overcome generator inertia more effectively than the square blades, even when no mechanical assistance is present. While the no-tier system did not meet the minimum voltage output for practical USB charging, it provided valuable insight into blade-only dynamics and startup sensitivity.

7.4. Comparison

Throughout the testing process, the Portable Wind Power Charger was evaluated across three mechanical configurations—two-tier, one-tier, and no-tier—to assess how drivetrain design and blade geometry affected energy output, startup behavior, and voltage stability. Each test provided insight into how internal resistance, wind speed, and aerodynamic efficiency shaped system performance.

In the two-tier configuration, which used two stacked planetary gear stages to maximize rotational amplification, the square blade outperformed the curved blade in both voltage and energy output. The square blade reached a peak average voltage of ~0.71V at 52 mph, while the curved blade achieved only ~0.441V at 47 mph. Additionally, in the controlled test conducted at 20 mph, the square blade delivered 0.0521 watt-hours, narrowly surpassing the curved blade's 0.104 watt-hours. This setup demonstrated that when mechanical advantage is maximized through gearing, the square blade can perform competitively due to its high torque response at elevated wind speeds.

In the one-tier configuration, which included only a single planetary gear stage, the curved blade delivered higher peak voltage performance, especially under loaded conditions. It achieved 3.39V at 38 mph (loaded), while the square blade was limited to ~0.71V. Despite these improvements in voltage, energy output over short test periods remained similar to the two-tier configuration, with the curved blade producing 0.104 watt-hours and the square blade 0.0521 watt-hours. The curved blade exhibited earlier startup and better stability, reinforcing its advantage under reduced-friction conditions.

In the no-tier configuration, where blades were directly coupled to the generator shaft with no gearing, the curved blade again demonstrated superior responsiveness. It generated 2.9V at just 30 mph, while the square blade required 40 mph to reach only ~1.1V. However, neither configuration sustained sufficient voltage output for five-minute energy testing. These results indicate that while both blades suffer from insufficient shaft speed in direct-drive mode, the curved blade's aerodynamic profile gives it a clear edge in environments where gearing is absent.

7.5. Summary

The performance of the Portable Wind Power Charger was evaluated across three mechanical configurations: two-tier, one-tier, and no-tier. These configurations allowed for controlled testing of how internal gearing and blade geometry influenced startup behavior, rotational smoothness, voltage regulation, and energy output. The results showed clear distinctions in performance between blade types and system configurations, particularly with respect to mechanical resistance and electrical reliability.

In the two-tier configuration, which used two stacked planetary gear stages to maximize rotational amplification, the square blade demonstrated higher average voltage output and slightly greater energy generation than the curved blade. At peak conditions, the square blade produced approximately 0.71 volts at 52 miles per hour and delivered 0.0521 watt-hours during testing at 20 miles per hour. The curved blade reached a maximum of 0.441 volts at 47 miles per hour and yielded similar energy over the same test window. However, both blade types suffered from startup delays due to compounded drivetrain friction, with the curved blade offering smoother acceleration despite its lower voltage output.

The one-tier configuration, which employed only a single planetary gear stage, shifted performance in favor of the curved blade. With reduced internal friction, the curved blade was able to reach 3.39 volts at 38 miles per hour under load and delivered a stable 5V output through the regulation system. Importantly, this was the only configuration that successfully powered and charged a mobile phone through the USB-C port, making it the only test setup that fully met the project's functional requirements. The square blade, by contrast, continued to struggle with delayed startup and only produced usable voltage under high-wind conditions.

In the no-tier configuration, which mounted blades directly onto the generator shaft with no gearing, the curved blade again outperformed the square blade in startup and voltage generation. The curved blade reached 2.9 volts at 30 miles per hour, while the square blade peaked at 1.1 volts at 40 miles per hour. However, without rotational amplification, neither setup sustained sufficient voltage for USB regulation, and five-minute energy testing could not be completed. These results highlight the curved blade's aerodynamic efficiency, but also demonstrate the limitations of direct-drive systems when using small generators with moderate torque requirements.

Overall, the one-tier configuration with the curved blade proved to be the optimal solution. It was the only system that achieved all key performance objectives: fast startup, stable rotation, effective voltage regulation, and successful charging of a real-world device. These results emphasize the importance of matching blade design with drivetrain complexity, and show that moderate gearing combined with low-drag blades can yield high-performance results in portable wind energy systems if not the lower wind speeds as wanted.

8. User Guide

This section outlines the contents of the user guide provided with the turbine. It includes step-by-step assembly instructions, safety precautions, and operational guidelines. The guide is designed to ensure users can safely and effectively deploy and operate the turbine in various outdoor conditions.

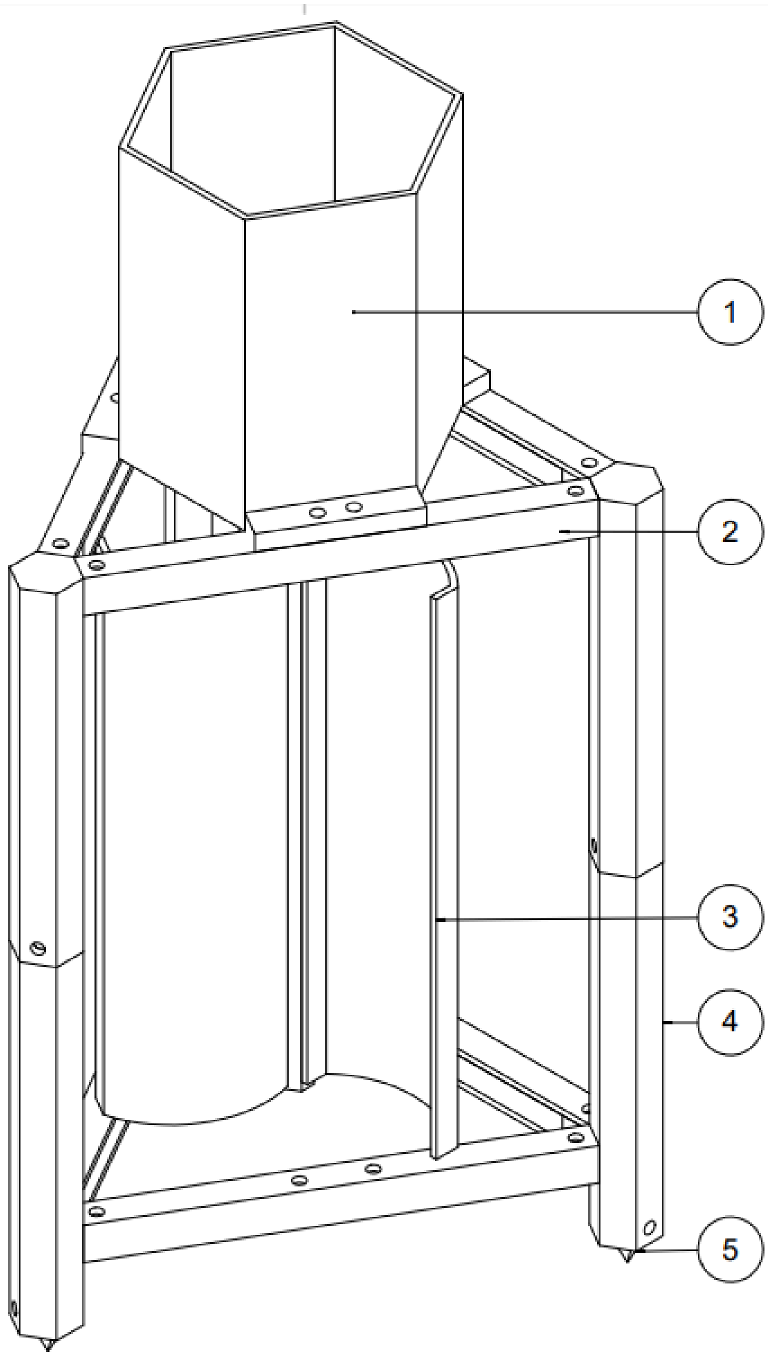

Figure of the standing Portable Wind Power charger.

8.1. Introduction

Thank you for choosing the Portable Wind Power Charger (PWPC). This guide provides step-by-step instructions for assembly, operation, maintenance, and safety precautions to ensure optimal performance and longevity.

8.2. Components overview

The generator consists of three main sections, each comprising multiple components:

Electronics: The internal circuitry responsible for power regulation and output. This section includes:

- 1 Generator
- 1 Buck converter with USB output
- 1 Boost converter
- 6 units of Wiring and connectors

Housing and Structure: The protective casing and support stand that provides stability and durability. This section includes (in parenthesis the part in the Figure):

- Outer shell made from 3D printed water-proof material (1)
- Structural frame to support the generator
    - 3 vertical stands female (4)
    - 3 vertical stand male (above 4)
    - 6 Horizontal cross beams (2)
    - 3 Hooks (5)
- 44 Fastening components (bolts and screws)

Turbine: The rotating blades that capture wind energy, converting it into mechanical power. This section includes:

- Blade assembly
    - 3 blades (3)
    - 1 rod
    - 1 shaft connector
- 1 Bearing system to minimize friction

8.3. Assembly Instructions

Unpacking

1. Carefully remove all components from the packaging.
2. Verify that all parts are included based on the provided checklist.

Setting Up the Turbine

1. Secure the stand on a stable surface using the provided mounting pieces.
2. Install the Turbine Blades
3. Connect the Electronics. Ensure all electrical connections are properly aligned.
4. Use the provided cables to connect the generator to your devices.
5. Ensure all bolts and connections are tight and secure before operation.

8.4. Operating Instructions

- Position the turbine in an open area with sufficient airflow (minimum wind speed: 5 mph).
- Allow the blades to rotate freely.
- The turbine will generate power automatically once operational.
- Connect your electronic devices via the USB-C output.
- Monitor charging indicators for power status.
- If wind energy is insufficient, use the manual crank to generate power.

8.5. Safety precautions

- Ensure all components are properly assembled before use.
- Do not expose electronics to water unless specified as waterproof.
- Avoid placing hands or objects near rotating blades.
- Secure the turbine in extreme weather conditions to prevent damage.
- Regularly inspect components for wear or damage.

8.6. Maintenance and Troubleshooting

8.6.1. Routine Maintenance

- Clean blades and housing regularly to remove debris.

- Check electrical connections for corrosion or loose fittings.
- Lubricate moving parts as needed to reduce wear.

8.6.2. Troubleshooting Common Issues

Issue	Possible Cause	Solution
No power output	Loose connection	Check and secure all connections
Blades not spinning	Insufficient wind flow	Relocate to a better position
Device not charging	Voltage fluctuation	Use a voltage regulator or ensure proper connection

8.7. Storage and Transport

- Disassemble and store in a dry, secure place when not in use.
- Use the provided carrying case for safe transportation.

8.8. Support

Call to this phone number or email us at PWPC@hotmail.com* (does not exist).

9. Conclusion

Outdoorsy people require a reliable and portable power solution to stay connected while exploring remote, off-grid locations. Wind generators offer a practical alternative when sunlight is unavailable, providing a reliable energy source in diverse natural environments. This innovative solution ensures they can charge devices and maintain connectivity, even in areas where solar power isn't an option

The prototype met most of the key design requirements. The system achieved a stable 5V output, remained under the target weight of 10 lbs, occupied less than 8.5 liters in packed volume, and was deployable within the 10-minute setup constraint. However, it did not fully meet the energy generation target of 6–10 Wh over 4–5 hours, nor did it perform optimally within the intended wind speed range of 5–30 mph, with best power generation observed only at 20–52 mph.

Performance testing revealed that blade shape significantly influenced efficiency and reliability. The curved blade outperformed the square design, demonstrating faster startup and greater energy output in low wind conditions (0.104 Wh in 5 minutes versus 0.0521 Wh for the square blade). This suggests that aerodynamic profile is a key factor in optimizing energy harvesting under variable environmental conditions.

Furthermore, increased wind speed consistently improved power output across all configurations, though the curved design maintained superior performance even at lower tiers. These observations highlight the importance of both mechanical design and environmental adaptability when engineering compact, off-grid wind energy solutions.

9.1. Future Recommendations

The following issues are left open for future students to improve upon the completion of this project.

Having this project be multidisciplinary with electrical and mechanical majors working together would help to fill the gaps of knowledge that either discipline would be missing. This would also allow each discipline to focus on the part of the project that is best suited to their skillset, likely leading to an increase in work efficiency and higher quality designs of project parts overall.

Test results highlight the significant impact of blade shape on system performance. Specifically, the curved blade demonstrated superior performance in low-wind conditions, providing faster startup, more consistent output, and greater overall efficiency compared to the square design. The blade designs in this project were made with only a general understanding of how a vertical wind turbine blade should be designed. A more in depth understanding of the characteristics of turbine blades would undoubtedly result in better blade design. More research into how wind turbine blades are designed is highly recommended.

One of the leading factors believed to cause the system to be less effective/efficient was the amount of friction present. The majority of friction in the system was caused by both the gearbox used and the generator itself. Additionally DC generators are not typically very efficient.

For a better gearbox, consider looking into prefabricated units. Specifically gearboxes that use nylon or ceramic gears would be preferred. These types of gears have less friction, are quieter, and much lighter than metal gears. Both are commonly used in high torque applications. Ceramic gears offer high temperature resistance and some vibration reduction while nylon gears are much lighter and better at absorbing vibrations.

DC generators, like the one used in this project, have a lot of inherent friction due to the commutators and typically have a low efficiency. While the efficiency of the generator in this project was not measured, DC generators typically have an efficiency ranging between 50-80%. A much better option to solve these issues would be to use a brushless DC (BLDC) generator. The name for this generator is a bit misleading as it actually outputs a 3 phase AC signal. BLDC generators typically have an efficiency ranging between 80-95%, much higher than that of a DC generator. Additionally these types of generators don't have a commutator, hence the name brushless, which lowers the friction introduced into the system. This would also mean that these generators are easier to drive and would require less torque to start and maintain rotation of the generator shaft. Another thing that's nice about BLDC generators is that the coils of the generator core are much more accessible. This means that if a generator doesn't have the characteristics that you want you could rewire the core of the generator with a different number of turns to change the voltage generated. It would be extremely beneficial to research winding patterns before attempting and take note of the number of stator poles and magnetic poles your generator has as this directly affects how you wind your coils. The 3 phase connection of a BLDC generator must also be considered. Because BLDC generators are 3 phase machines they can either be connected using a wye, also called star, connection or delta connection. Depending on the connection used it will change the magnitude of the voltages and currents generated. Having a good understanding of 3 phase systems is paramount to taking advantage of this characteristic of the BLDC generator. Unfortunately, the BLDC generator being an AC machine means that to get a DC signal a rectifier is required. While this isn't a huge issue as rectifiers aren't necessarily hard to design, it is another component added to the system that increases the overall complexity. Rectifiers will also reduce the efficiency of the system slightly, however using high quality diodes will mitigate these losses. Regardless, the added efficiency of the BLDC generator will ensure that it outperforms the DC generator.

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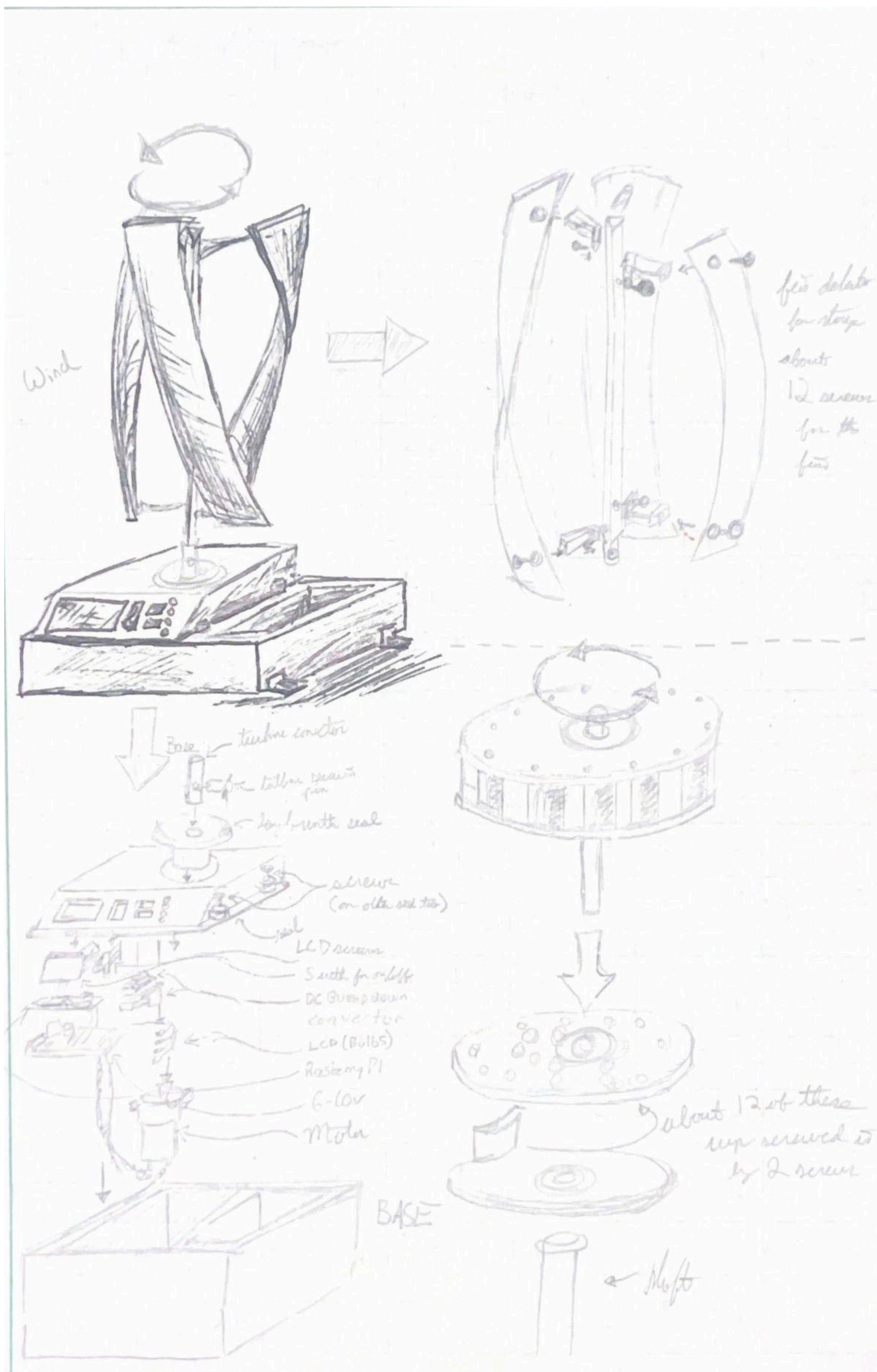
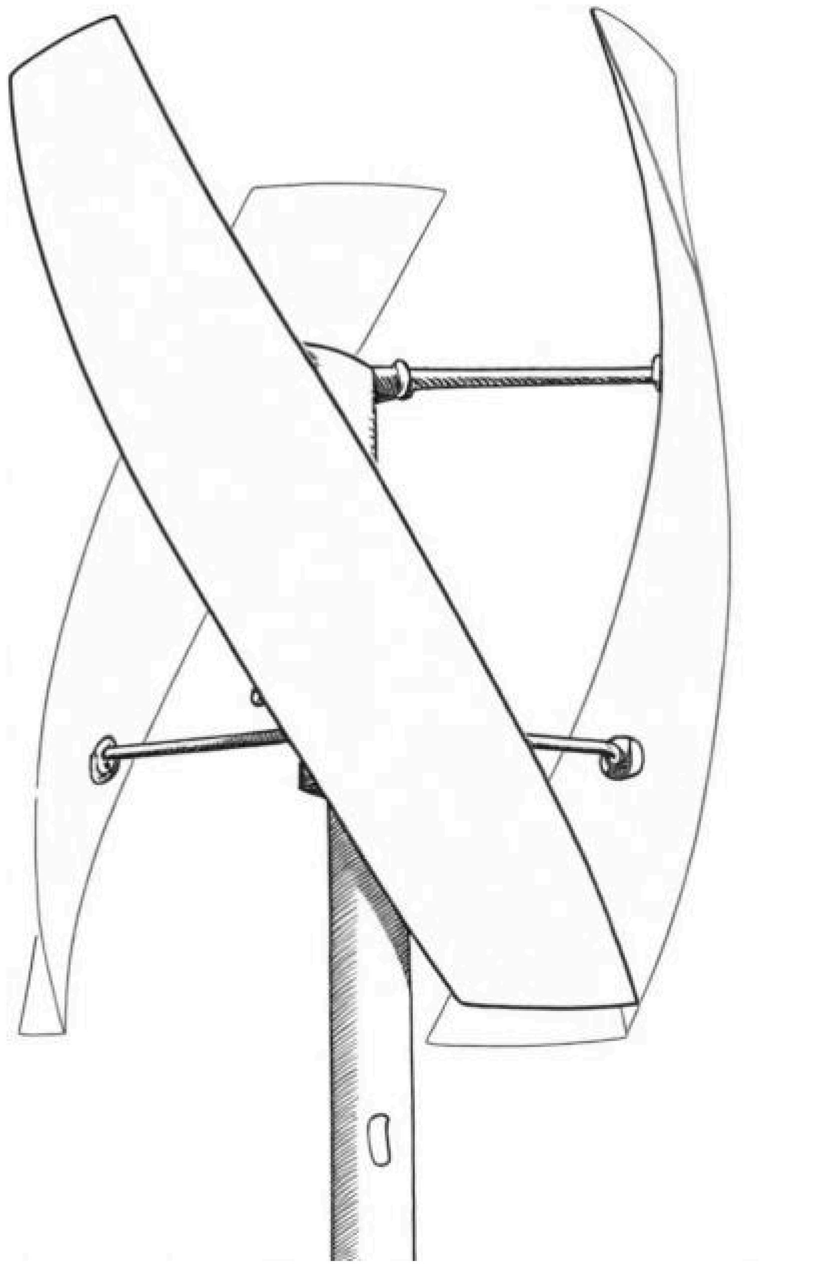
11. Appendixes.

Appendix A. Design drawings

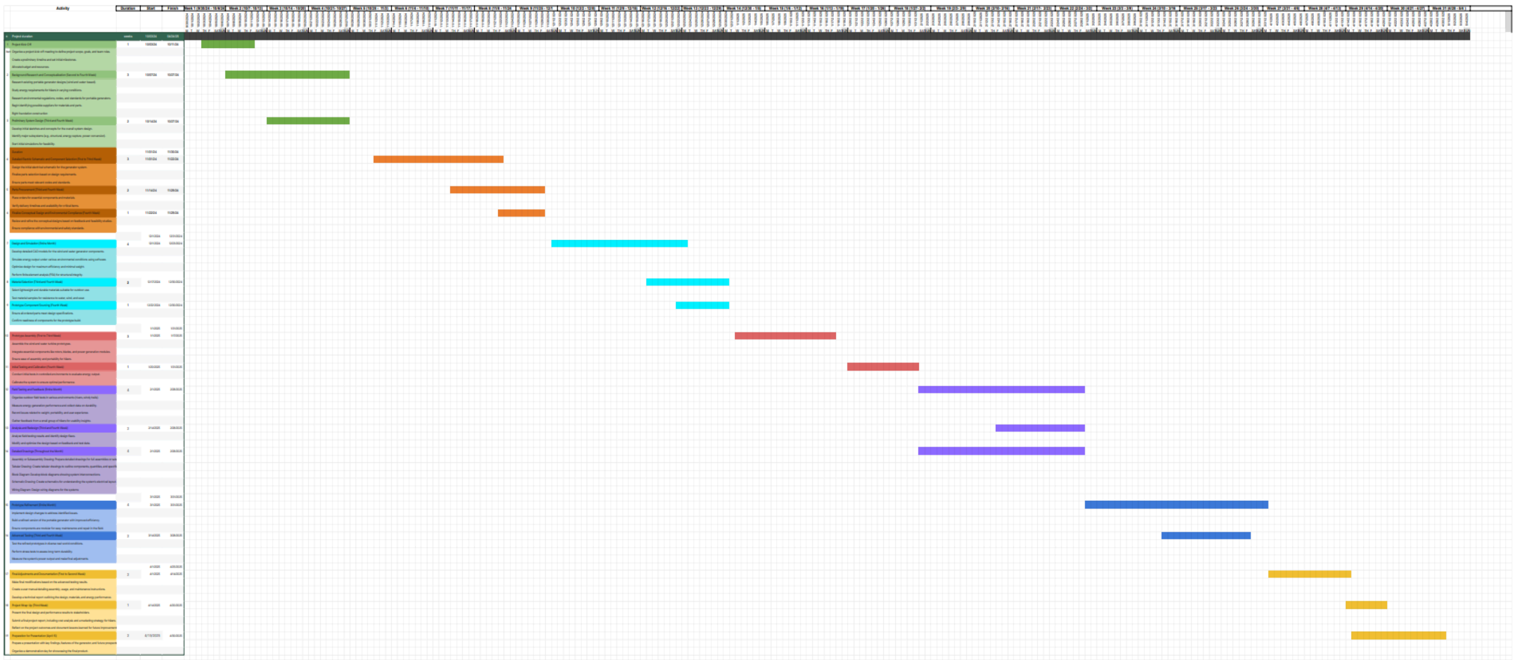


Appendix B. Blades design

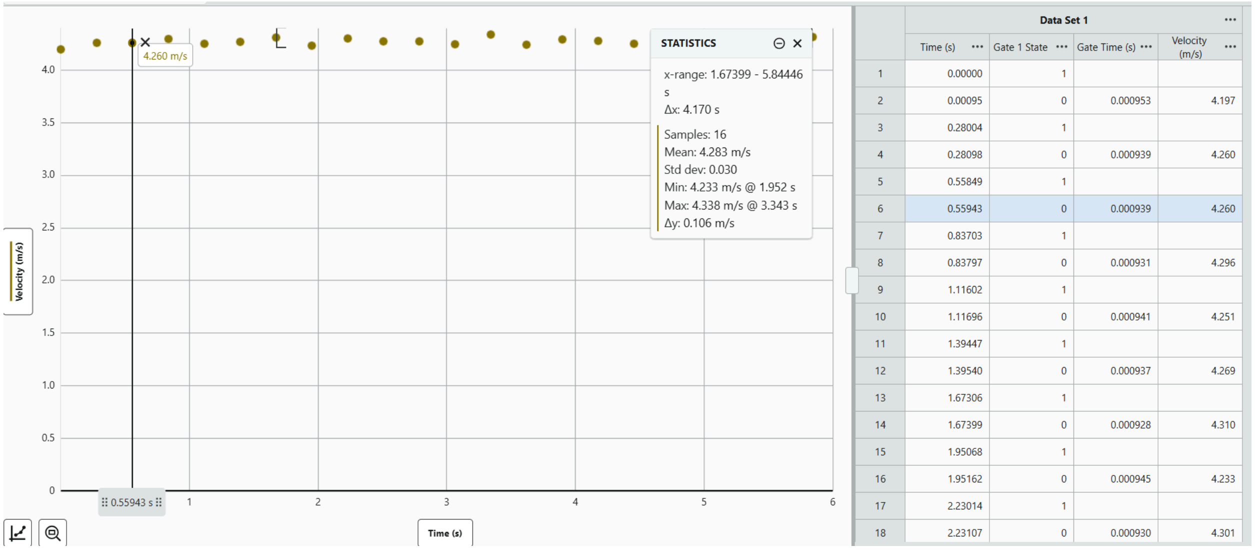


Appendix C. Schedule of Project

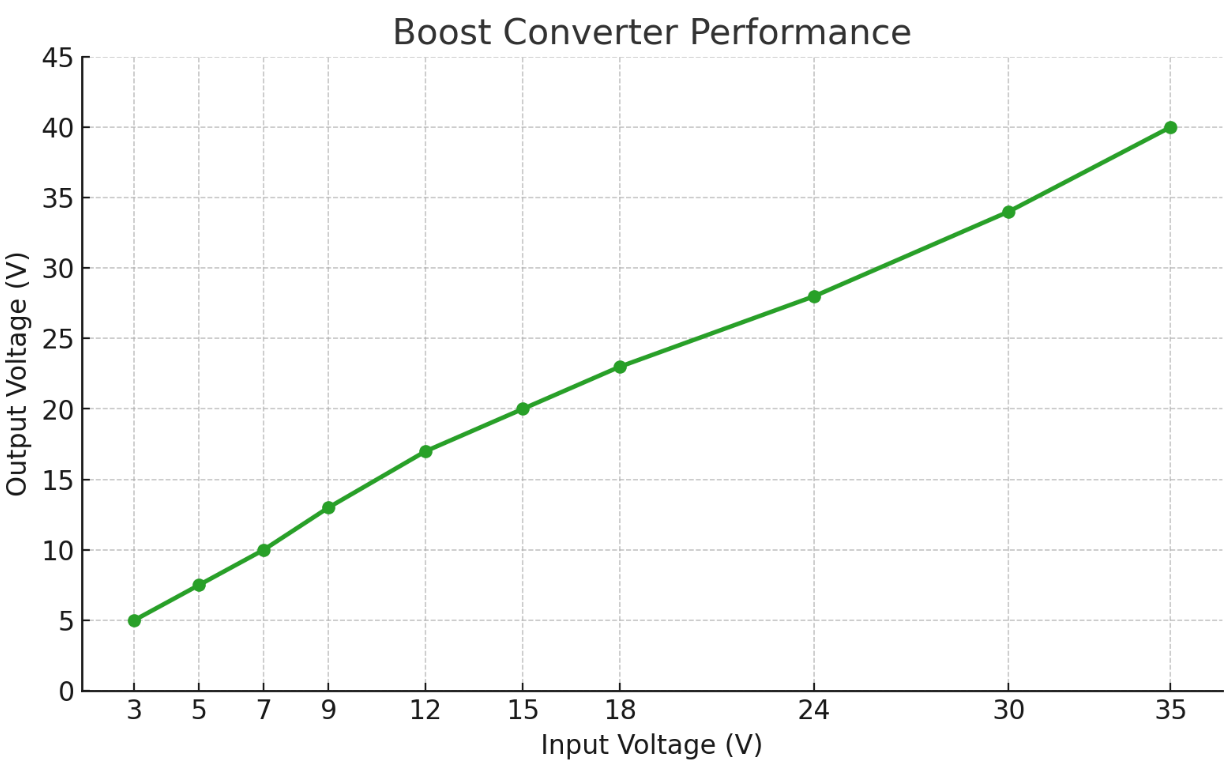
See the complete Schedule in this Link

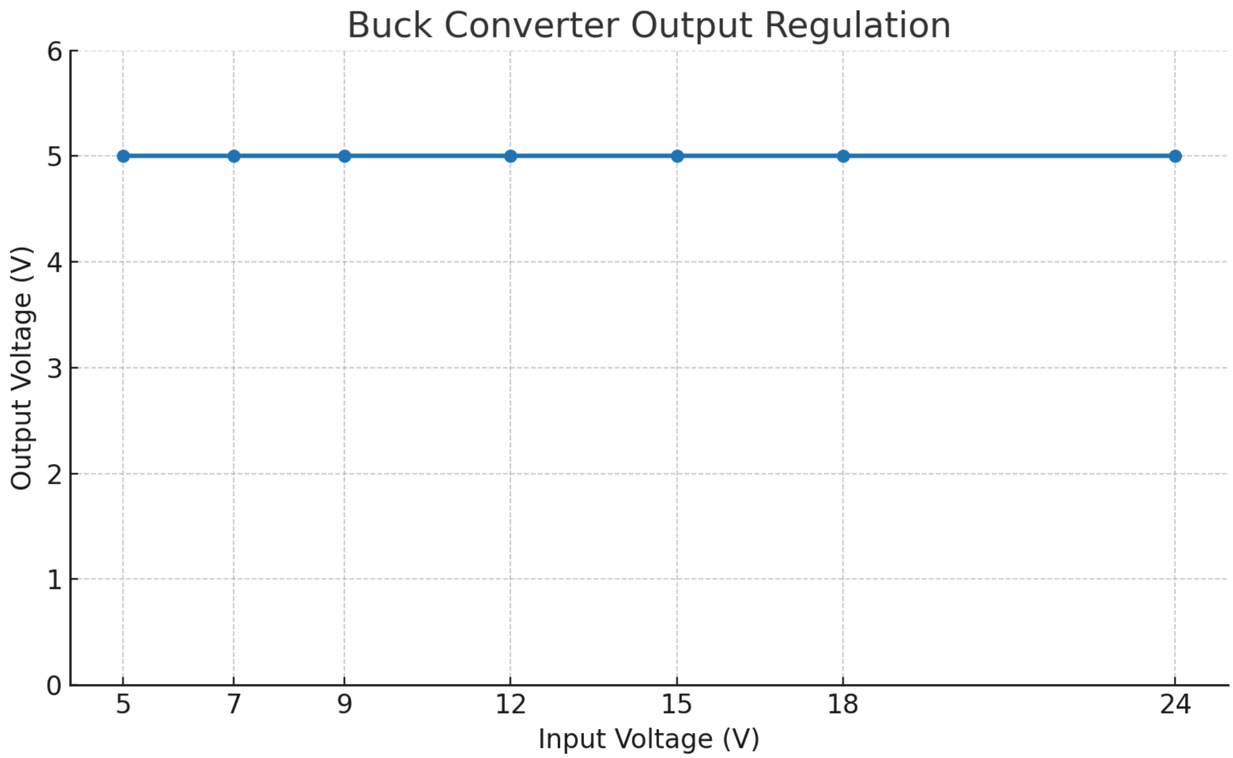


Appendix D. Graphs of tests.



	Time (s)	Gate 1 State	Gate Time (s)	Velocity (m/s)
1	0.00000	1		
2	0.00095	0	0.000953	4.197
3	0.28004	1		
4	0.28098	0	0.000939	4.260
5	0.55849	1		
6	0.55943	0	0.000939	4.260
7	0.83703	1		
8	0.83797	0	0.000931	4.296
9	1.11602	1		
10	1.11696	0	0.000941	4.251
11	1.39447	1		
12	1.39540	0	0.000937	4.269
13	1.67306	1		
14	1.67399	0	0.000928	4.310
15	1.95068	1		
16	1.95162	0	0.000945	4.233
17	2.23014	1		
18	2.23107	0	0.000930	4.301




Buck Converter Output Regulation
Output Voltage (V)
Input Voltage (V)
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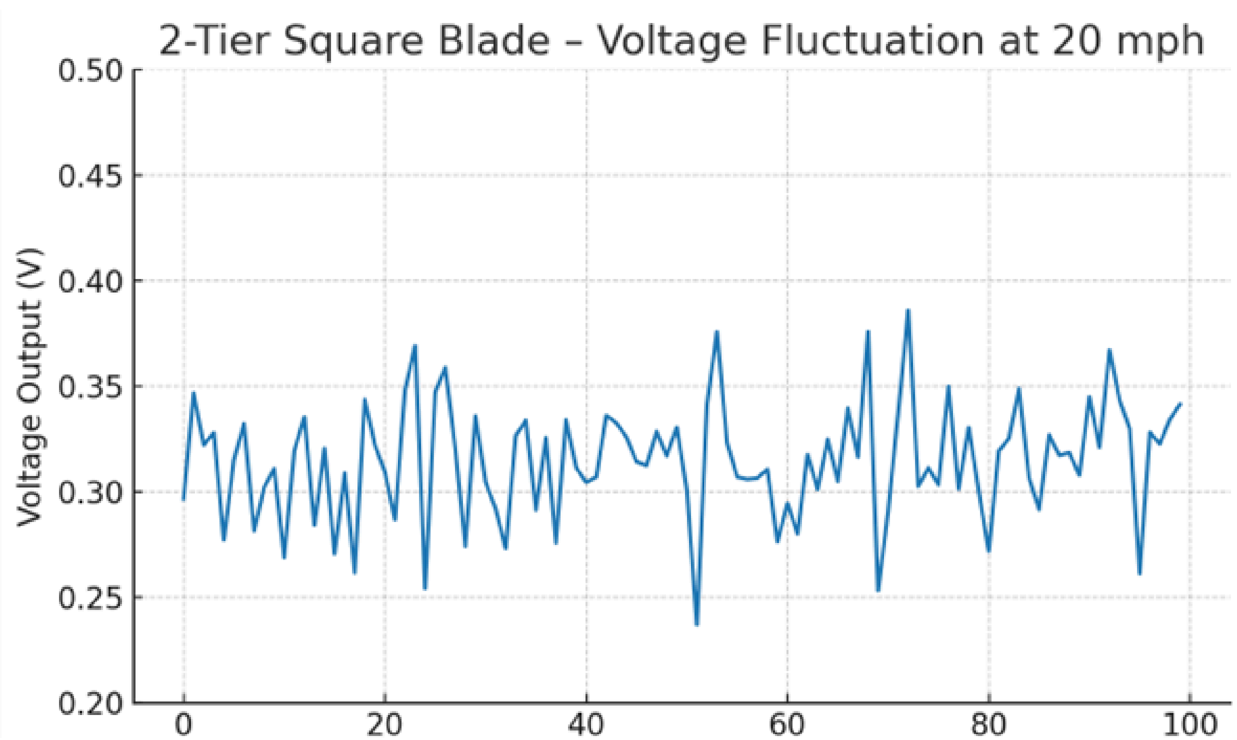
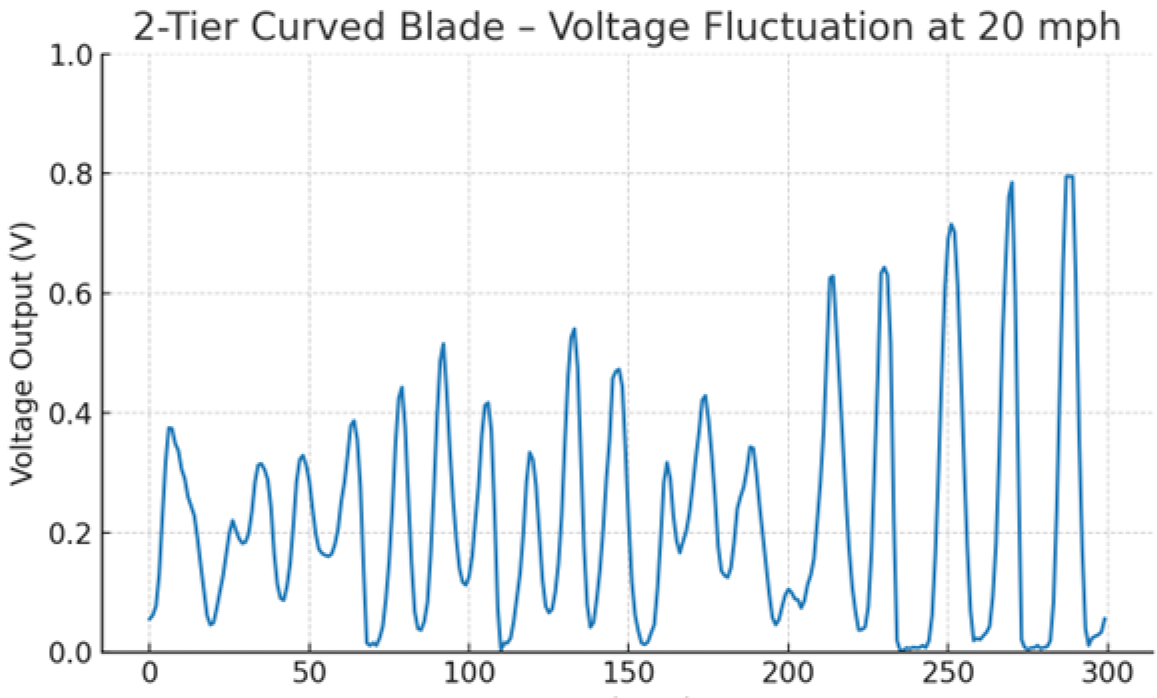
1
2
3
4
5
6
5
7
9
12
15
18
24


2-Tier Square Blade – Voltage Fluctuation at 20 mph
Voltage Output (V)
0.20
0.25
0.30
0.35
0.40
0.45
0.50
0
20
40
60
80
100


2-Tier Curved Blade – Voltage Fluctuation at 20 mph
Voltage Output (V)
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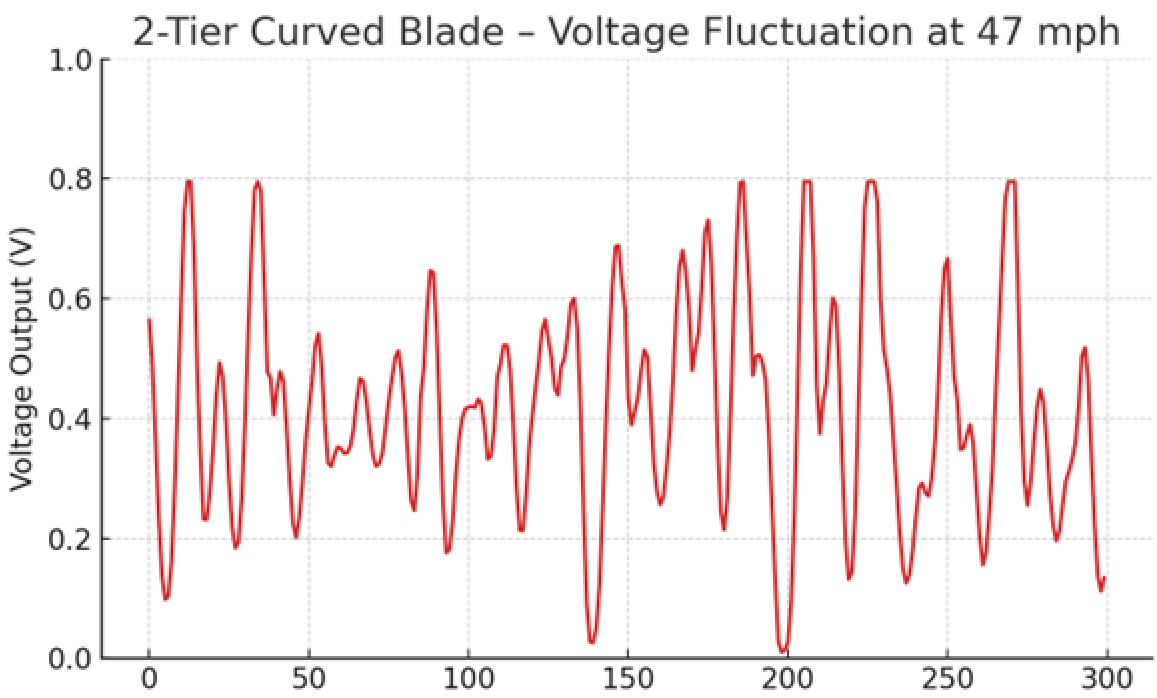
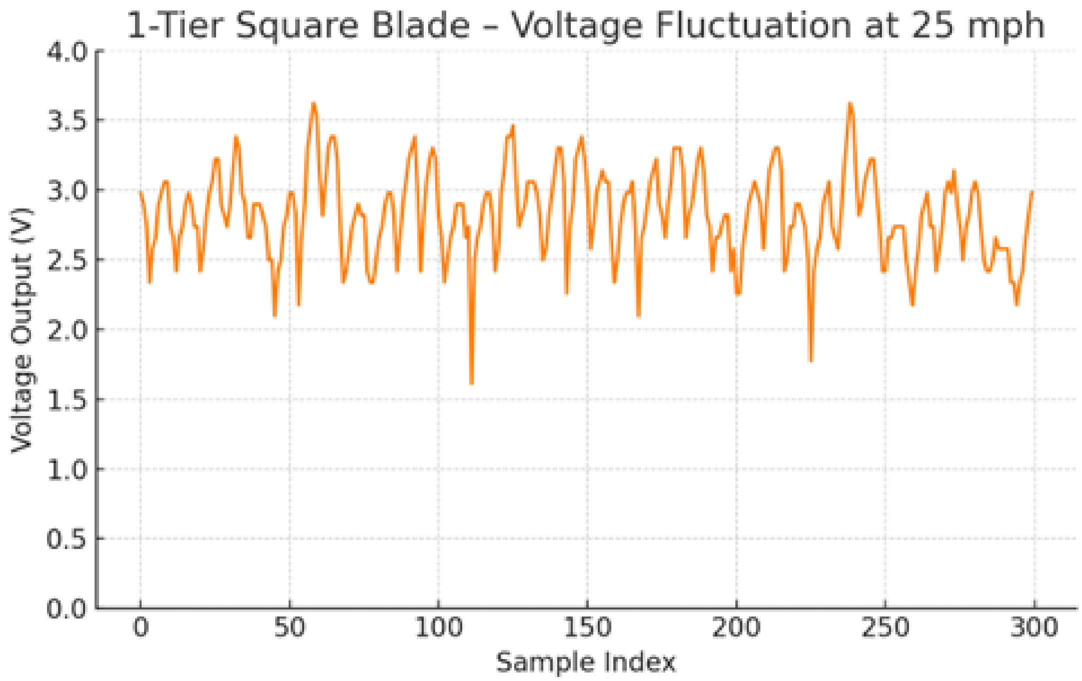
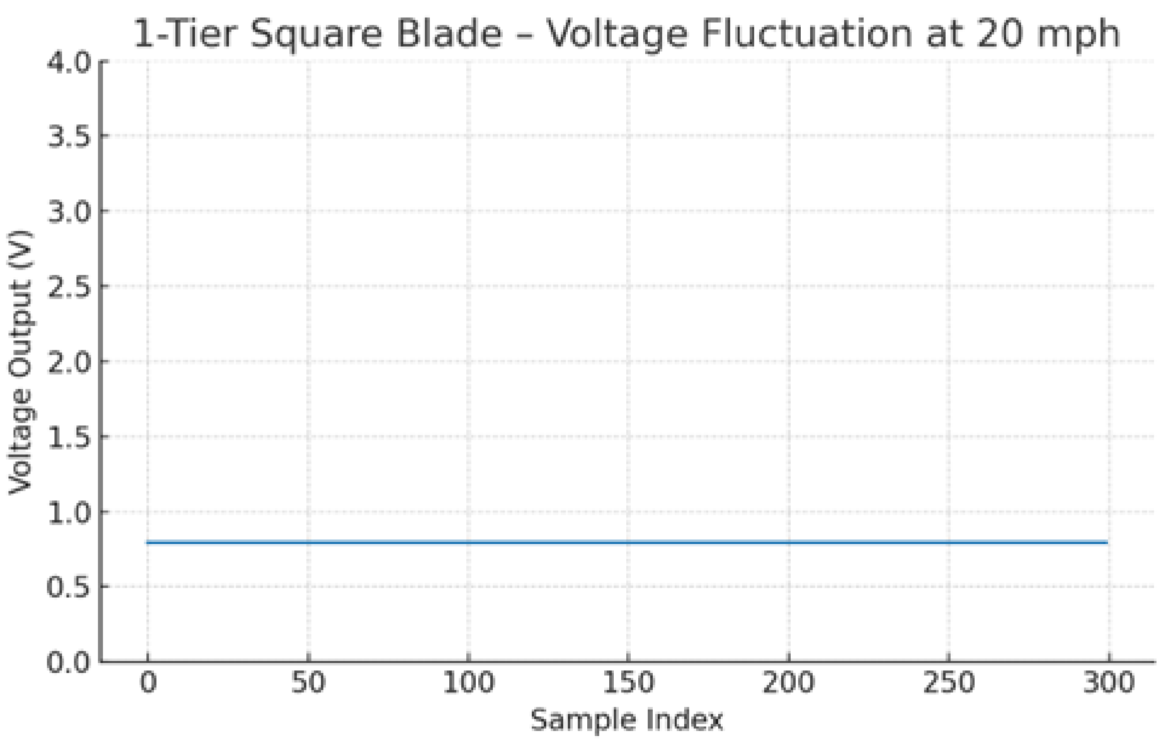
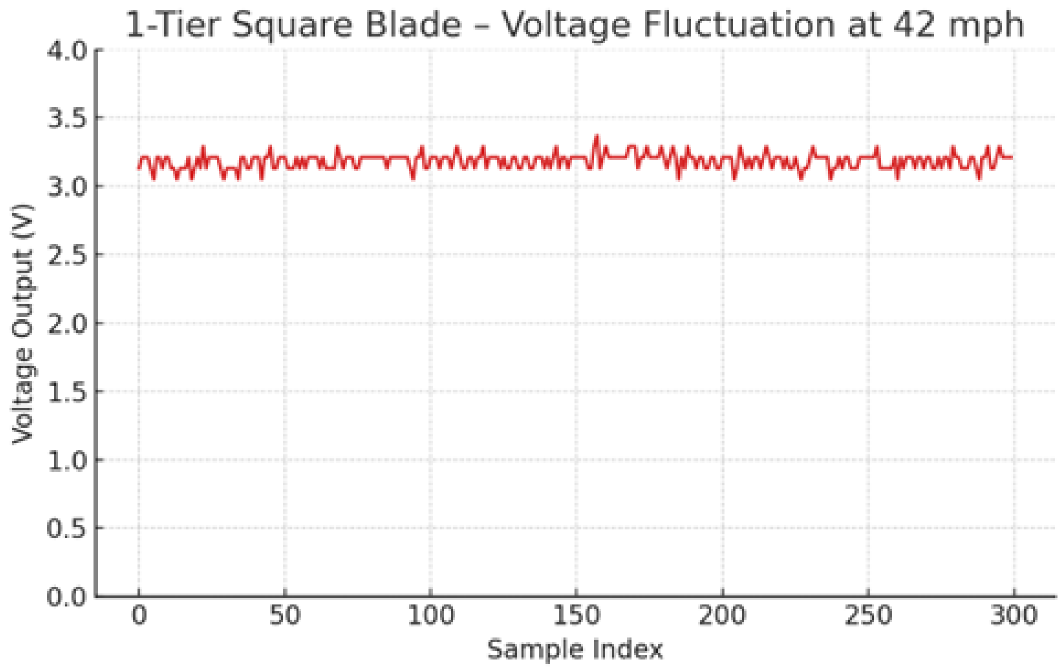
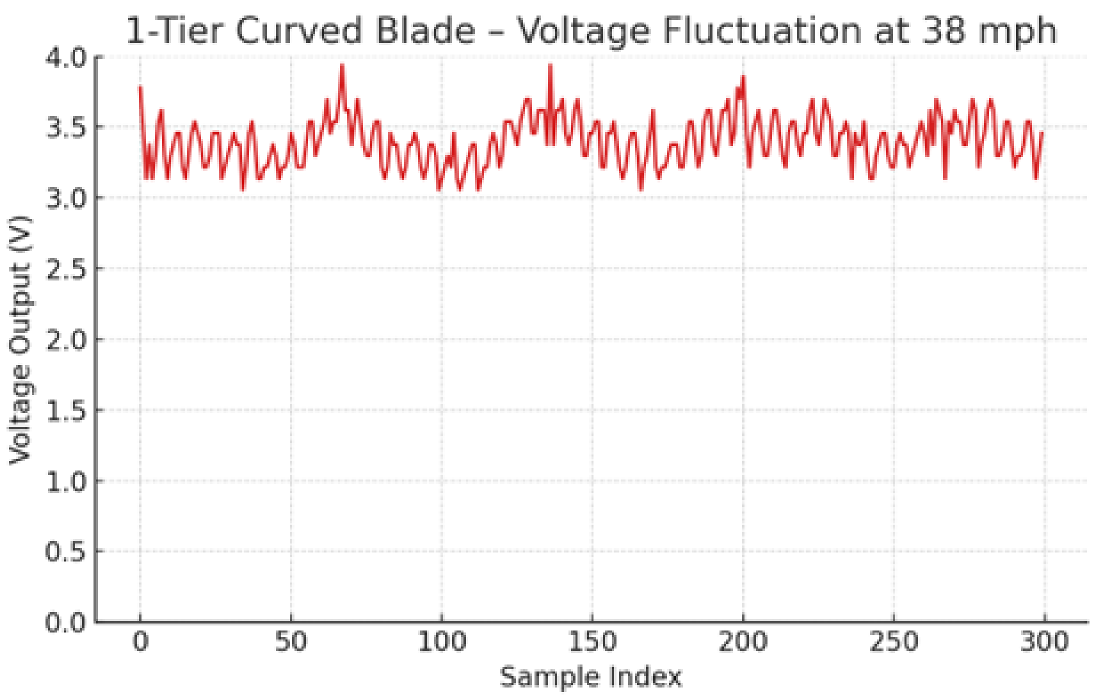
0.8
0.6
0.4
0.2
0.0
0
50
100
150
200
250
300

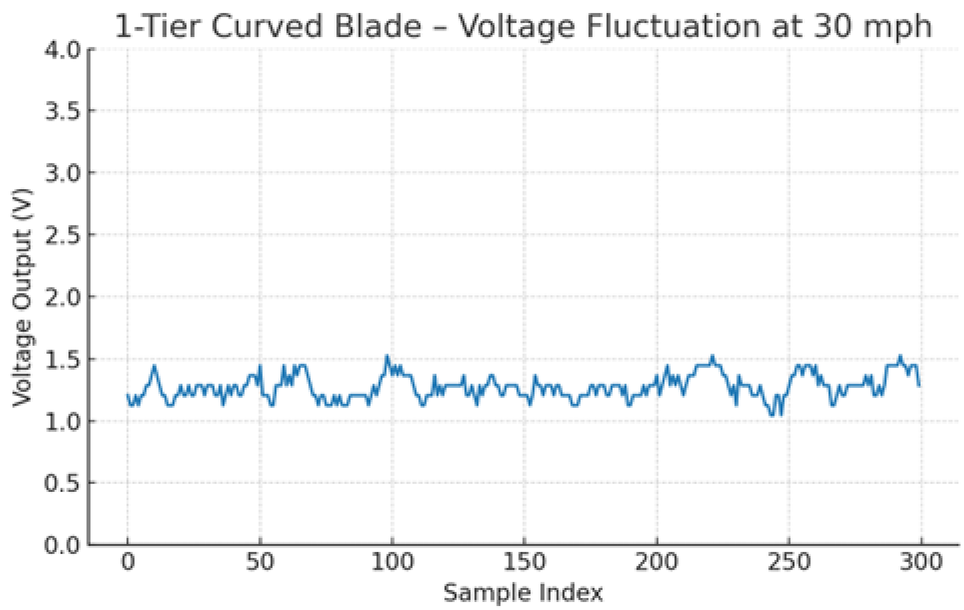

2-Tier Curved Blade – Voltage Fluctuation at 47 mph
Voltage Output (V)
1.0
0.8
0.6
0.4
0.2
0.0
0
50
100
150
200
250
300

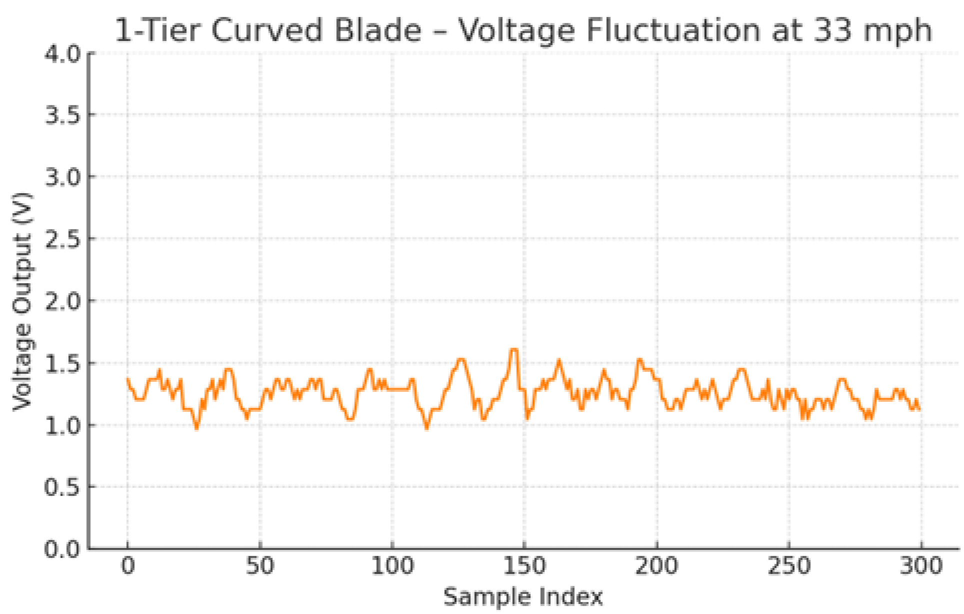

1-Tier Square Blade – Voltage Fluctuation at 25 mph
Voltage Output (V)
Sample Index
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
50
100
150
200
250
300

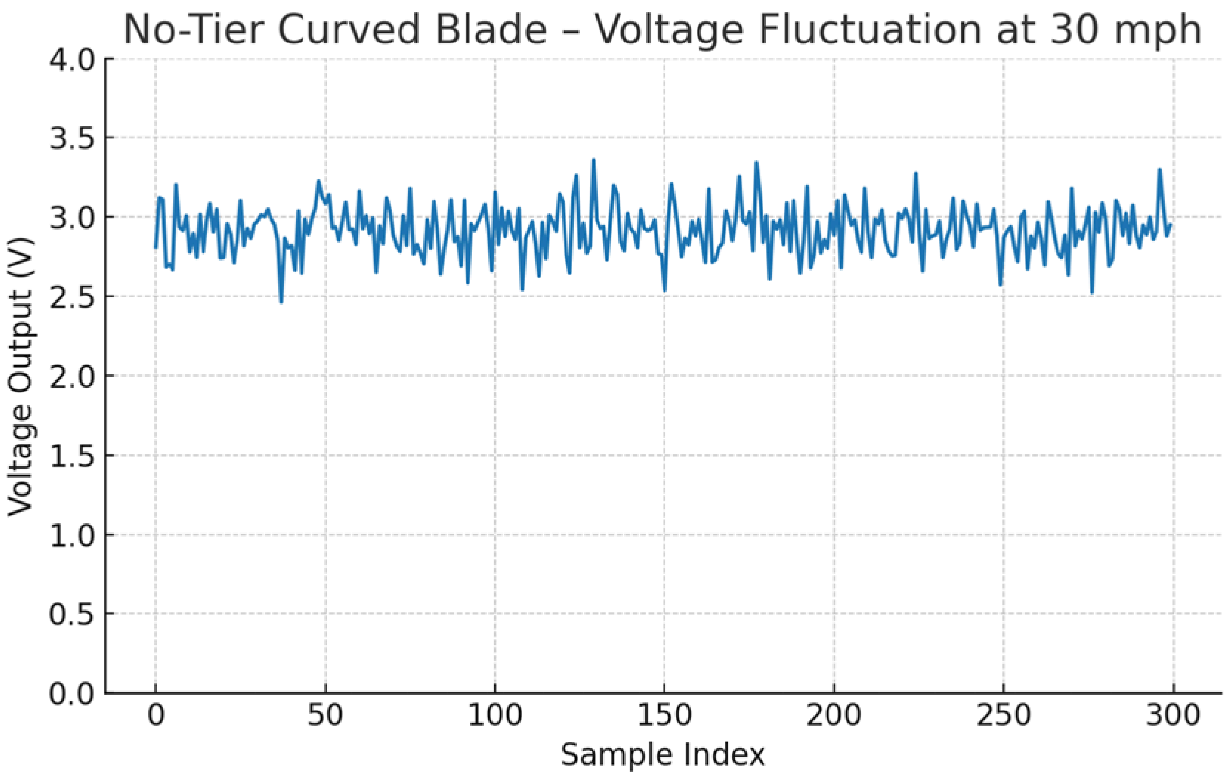

1-Tier Square Blade – Voltage Fluctuation at 20 mph
Voltage Output (V)
Sample Index
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
50
100
150
200
250
300

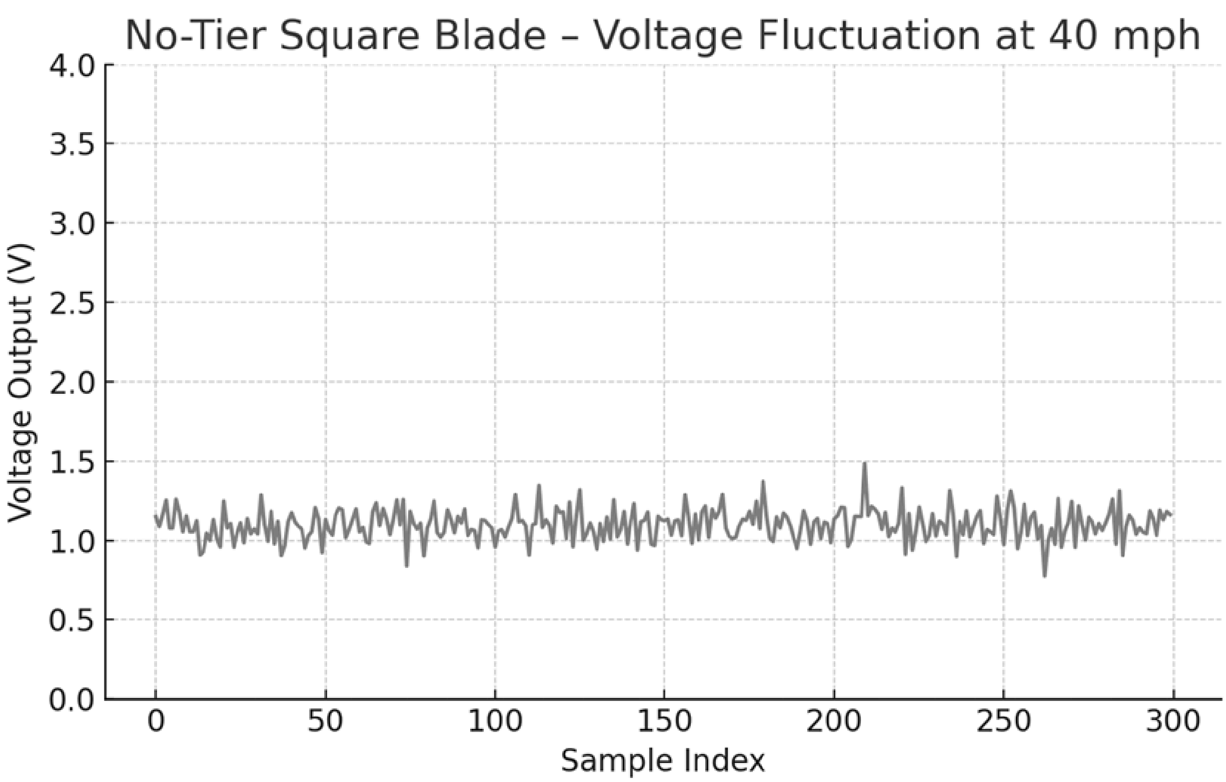

1-Tier Square Blade – Voltage Fluctuation at 42 mph
Voltage Output (V)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
50
100
150
200
250
300
Sample Index


1-Tier Curved Blade – Voltage Fluctuation at 38 mph
Voltage Output (V)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
50
100
150
200
250
300
Sample Index


1-Tier Curved Blade – Voltage Fluctuation at 30 mph
Voltage Output (V)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
50
100
150
200
250
300
Sample Index


1-Tier Curved Blade – Voltage Fluctuation at 33 mph
Voltage Output (V)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
50
100
150
200
250
300
Sample Index


No-Tier Curved Blade – Voltage Fluctuation at 30 mph
Voltage Output (V)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
50
100
150
200
250
300
Sample Index


No-Tier Square Blade – Voltage Fluctuation at 40 mph
Voltage Output (V)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
50
100
150
200
250
300
Sample Index

Appendix E. Level 0 with Water and Wind input flow

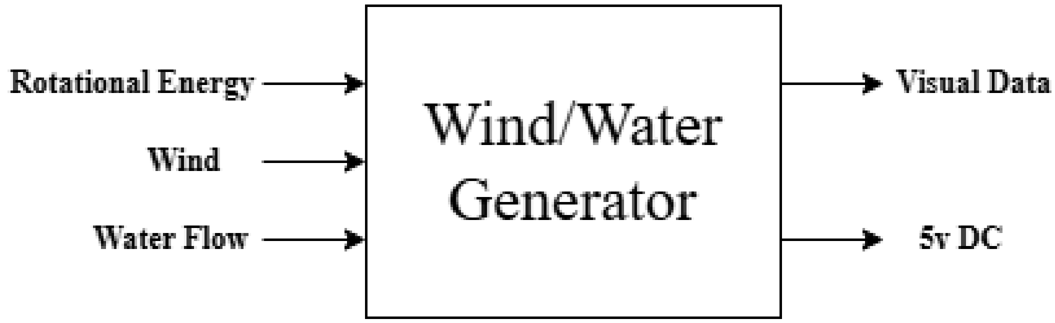


Figure 1: Level 0 Diagram

Module	Wind Generator
Inputs	• Rotational Energy - Wind, or hand crank • Wind
Outputs	• Visual Data - Digital Display • 5v DC
Functionalit y	Takes in rotational mechanical energy, as well as wind flow, and produces a steady 5v DC output as well as provide visual data to the user about the system and data collected.

Table E1: Wind Generator

Appendix F. Level 1 of improvement diagram.

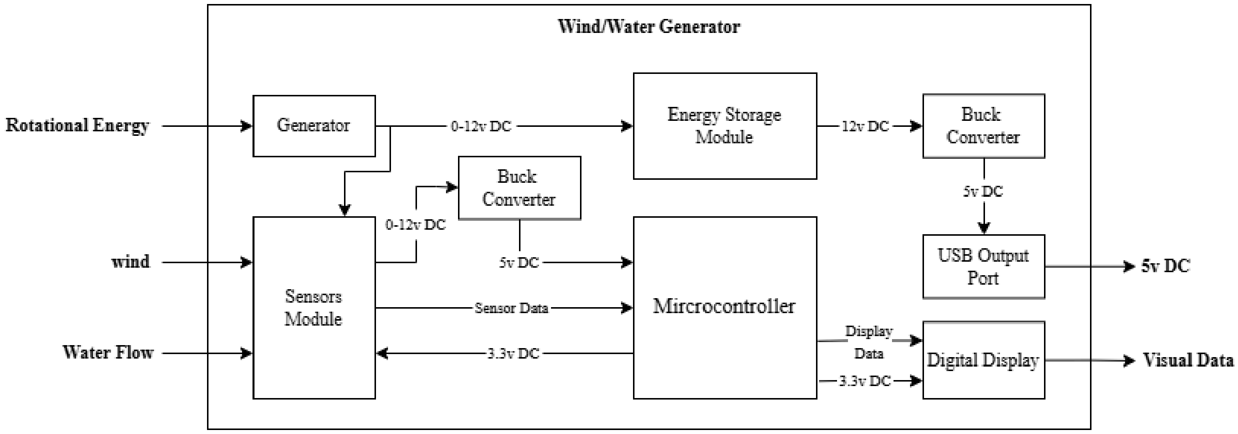


Figure F2: Level 1 Diagram

Module	Generator
Inputs	• Rotational Energy - Wind, water flow, or hand crank
Outputs	• 0-12v DC
Functionalit y	Takes in rotational mechanical energy and outputs a DC voltage between 0-12v.

Table F2: Generator

Module	Sensors Module
Inputs	• Wind • Water flow • 0-12v DC (from generator) • 3.3v DC
Outputs	• 0-12v DC • Sensor Data
Functionalit y	Provides sensor data for the system by measuring wind speeds, water flow rates, generator rotational speed, and power produced from the generator. The various sensors are powered by the 3.3v input.

Table F3: Sensors Module

Module	Buck Converter
Inputs	• 0-12v DC
Outputs	• 5v DC
Functionalit y	Converts a higher voltage to a lower, more usable voltage. Typically, 12v to 5v in this system application.

Table F4: Buck Converter

Module	Energy Storage Module
Inputs	• 0-12v DC (from generator)
Outputs	• 12v DC
Functionalit y	Takes in 0-12v DC power from the generator and stores it in a battery using a charge controller. The controller will try to maintain the battery voltage at 12v.

Table F5: Energy Storage Module

Module	Microcontroller
Inputs	• 5v DC • Sensor Data
Outputs	• 3.3v DC • Display Data
Functionalit y	The microcontroller will be the brain of the system, taking in data from the system sensors, running calculations, and sending data to the display to be output to the user.

Table F6: Microcontroller

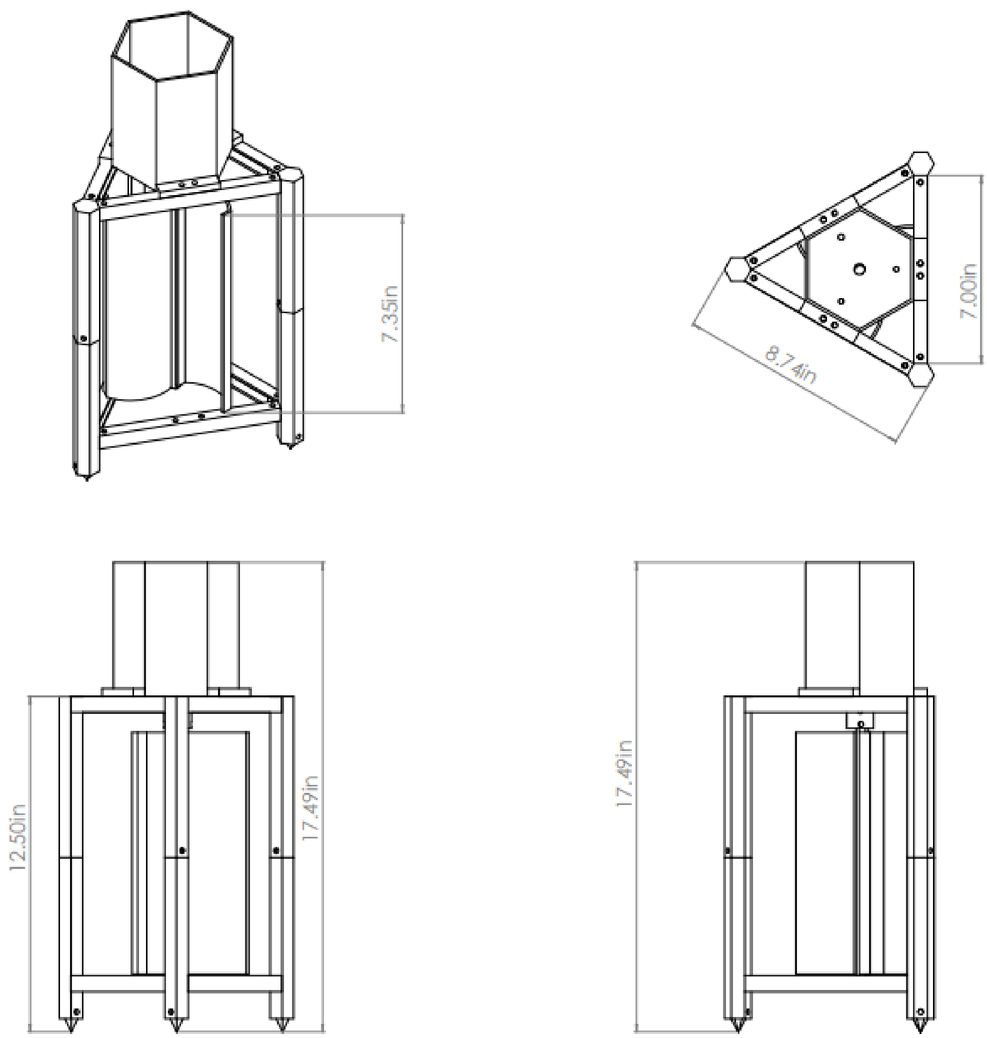
Module	Digital Display
Inputs	• 3.3v DC • Display Data
Outputs	• Visual Data
Functionalit y	The display will receive display data and 3.3v DC power both from the microcontroller and output visually to the user based on the display data received.

Table F7: Digital Display

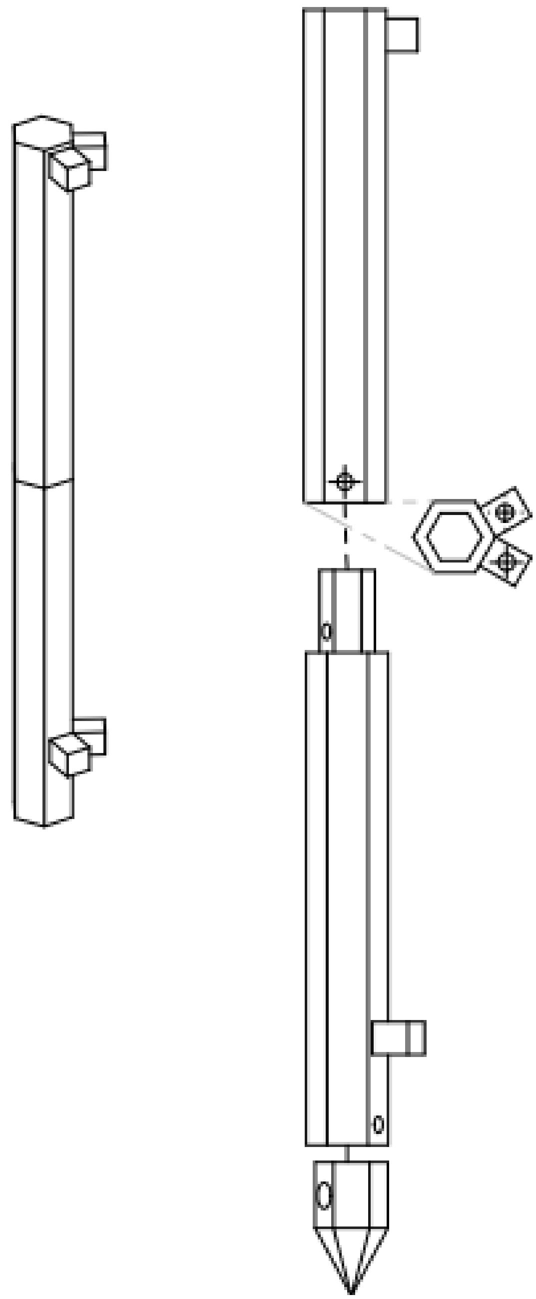
Module	USB Output Port
Input	• 5v DC
Output	• 5v DC
Functionalit y	This module will both receive and output 5v DC power, however the output will be made easier to access for the user via a USB access port.

Table F8: USB Output Port

Appendix F. Full Assembly with curve blades.



Appendix G. Vertical support Disassembly.



Appendix F. Horizontal supports connection.