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Curriculum Design for Wind and Solar Energy Education

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Abstract

The proposed curriculum on wind and solar energy offers an educational opportunity to both undergraduate and graduate students, allowing them to acquire essential skills in renewable energy and engineering design. The primary objective of this curriculum is to expose and engage undergraduate students in interdisciplinary learning related to renewable energy. It provides them with a unique opportunity to expand their educational experiences and fosters a commitment to renewable energy. The long-term goal of this curriculum is to stimulate interest in learning and developing skills in renewable energy, especially in the context of West Virginia.

In this paper, we outline a curriculum that includes various courses in renewable energy. Additionally, we design the necessary infrastructure and instrumentation to facilitate measurements that aid in understanding the generation and delivery of energy from environmentally friendly sources such as wind and solar power. We propose a framework for developing an undergraduate curriculum that incorporates project-based concepts in power courses. This curriculum will create new learning materials and teaching strategies, with a particular focus on introducing renewable energy concepts in the early phases of power engineering courses. It will integrate wind and solar energy considerations, challenges, and concepts into all aspects of power engineering. The unique goal of this paper is to raise awareness of green energy in power systems and provide practical training for the much-needed industry sector.

Key Words: Curriculum Design, Wind Energy, Solar Energy, Wind Turbine Design, Global Challenges.

I. Introduction

The objective of this study is to create a curriculum that will provide the infrastructure for teaching the principles of green energy, demonstrating its benefits and challenges, and enabling it to be effective, efficient, and capable of generating sufficient electric energy to meet West Virginia's demands. West Virginia's economy heavily relies on coal-fired electric power, despite the accelerating decline in coal demand[1,2]. With the dramatic decline in coal energy and the devastating health and economic repercussions in communities across West Virginia, the demand for alternative energies has become even more pressing[3]. As a result, citizen education, training, and mobilization of personnel and the labor force are critical and essential for West Virginia to transition its resources toward wind and solar energy. Through this curriculum program, we aim to lay the groundwork for transforming West Virginia into a green state and provide a means for the education and training of the next generation of engineers who will lead in researching and advancing the capabilities of wind and solar energy to sustain West Virginia as coal-based energy fades away.

Coal, a highly abundant source of carbon, is a combustible sedimentary rock[4,5]. It also contains other elements, including hydrogen, sulfur, oxygen, and nitrogen, in small amounts. Coal is a nonrenewable energy source and is categorized into four ranks: anthracite, bituminous, subbituminous, and lignite. Anthracite coal has the highest heating value and contains 86% to 97% carbon. Anthracite accounts for fewer than 1% of all coal mined in the United States. Bituminous coal has a carbon content ranging from 45% to 86% and makes up about 44% of all U.S. coal production, making it the most prevalent rank in the country. Electricity is generated using bituminous coal, and at least 18 states produce it, with West Virginia accounting for 28% of total U.S. bituminous output. Subbituminous coal has a lower heating value and typically contains 35% to 45% carbon compared to bituminous coal. Lignite has the lowest energy content of all coal grades and includes 25% to 35% carbon. The majority of lignite is used to generate power. In the United States, coal is primarily used as a fuel for electricity generation, contributing to approximately 22% of all U.S. energy production in 2021[6]. The heat generated from burning coal is used to create high-pressure steam, which drives turbines and produces electricity[3]. The efficiency of coal combustion ranges between 25% and 50%, depending on coal pre-processing, turbine technology, and plant age[7]. Integrated gasification combined cycle (IGCC) power plants gasify coal to produce syngas, which is subsequently used to generate electricity, enhancing coal combustion[8]. However, the technology for capturing carbon during the process of coal gasification remains too expensive[9].

Coal mining and processing pollute the air and water, causing environmental damage and resulting in early deaths and illnesses[10-16]. Each year, massive amounts of coal ash and other coal byproducts are produced, with ash accounting for approximately 10% of all burned coal[17-19]. Coal burning is the primary anthropogenic source of carbon dioxide (CO2) and sulfur oxide (SO2) emissions, contributing to climate change and ecosystem acidification[20]. Acid rain was one of the first identified effects of coal on the water cycle. In the United States alone, it is estimated that 1,500 former coal industry workers die each year due to exposure to coal mine dust[21,22]. In 2018, coal-fired power stations were the single greatest contributor to the increase in worldwide CO2 emissions. Capturing CO2 emissions from coal remains economically unviable.

Despite the intricate dependence of the state of West Virginia on coal, alternative energy education is evolving through joint research between Marshall University and regional energy companies such as Marathon Power, Camelot Technologies Group (CTG) Power, TransCanada (TC) Energy, American Electric Power (AEP) Appalachian Power, and Solar Holter. The proposed curriculum is an effort to expose undergraduate and graduate students to the potential research opportunities at these institutions. Marshall University is committed to providing the intellectual and technological means to support the success of this curriculum and expanding education and research in renewable energy. As more renewable energy is integrated into existing conventional energy resources, the need for education and skills becomes more pronounced to fill the new positions required for the transition to a green future. This curriculum has been in development at Marshall University for several years, providing the necessary resources to establish an interdisciplinary core program. Thus, this paper will describe the components of a curriculum designed with a unique infrastructure to teach the skills required for understanding the concepts of green energy, specifically wind and solar energy. The curriculum will provide the necessary skills to train the next generation of the workforce that will drive West Virginia toward green energy.

II. Curriculum Design Description

The curriculum not only imparts a fundamental understanding of wind and solar energy[23,24] but also offers project-based learning experiences[25-27]. The curriculum includes projects to engage undergraduate students in collaborative and ethical research[28]. These project-based learning skills include extracting features from the complex vibrations of wind turbines for condition monitoring and dynamic control, modeling wind turbine-generator systems, applying classical control systems for maximum power point tracking and regulation for wind turbines, implementing expert control systems for maximum power point tracking and regulation for wind turbines[29], exploring bio-inspired wind turbines[30], designing blade-based solar electric energy generation[31], creating hybrid wind-solar energy control systems[32], and utilizing wind turbine video monitoring for bird fatalities. The objectives of designing this curriculum serve both short- and long-term purposes, allowing for the creation and delivery of the necessary knowledge. The objectives of this curriculum are:

- To design an infrastructure that enables the delivery of educational, training, and hands-on skills in all aspects of green energy.
- To create undergraduate and graduate courses with research and education skills commensurate with students' educational levels.
- To formulate a plan for skill-building and delivery in an interdisciplinary engineering curriculum, interfacing with existing courses on power and energy generation and distribution.
- To instill a sense of urgency for learning and training in green energy, addressing current, new, and future challenges, and responding to the urgent impacts of global warming on human health, the environment, and overall well-being.

The curriculum integrates diverse educational levels, faculty expertise, disciplinary areas, student backgrounds, industrial requirements, learning methodologies, and practical applications aligning with students' knowledge and available laboratory resources. Our framework includes essential components crucial for this curriculum's effective implementation. We identified three pivotal elements vital to its success: academic strategy, infrastructure, and research strategy. Educational objectives and course structure form the backbone of the curriculum, adapting specific learning outcomes aligned with students' engineering program levels. Courses are strategically designed to meet these objectives, ensuring a comprehensive educational journey for the student.

The infrastructure of the curriculum consists of faculty expertise, laboratory spaces, and requisite equipment essential for hands-on laboratory assignments and project-based learning. These elements are arranged to equip students with practical skills essential for their future roles in the workforce. The research component focuses on leveraging faculty expertise and research initiatives, this aspect fosters collaborative and comparative research in alignment with the university's, stakeholders', state and federal agencies', and private sector needs. This research-driven approach ensures relevance and innovation within the curriculum. Figure 1 illustrates how these components are integrated into the curriculum design, facilitating the comprehensive teaching of renewable energy across the engineering program. Moreover, the curriculum emphasizes an interdisciplinary approach, further enhancing the focus on renewable energy.

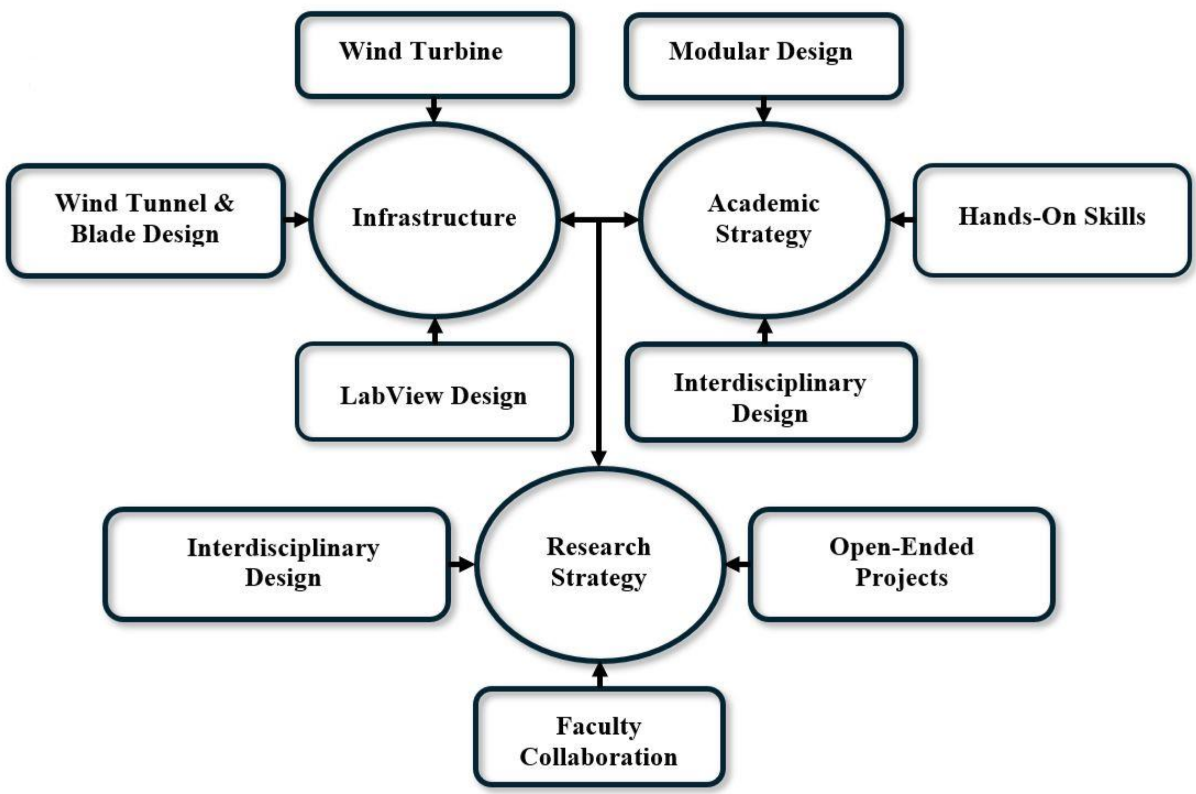

Figure 1: illustration of the strategic components implemented during the design of the curriculum.

III. Curriculum Infrastructure and Instrumentation

Wind and solar energy equipment is strategically distributed across the engineering laboratories to provide students with a comprehensive learning experience that combines theoretical knowledge with hands-on experimentation. This approach enriches their understanding of renewable energy systems, preparing them for the challenges and opportunities in the field. The core of our educational infrastructure is the industrial lab, which serves as a hub for innovation and practical training. Within this lab, students have access to a significant array of resources. Five wind turbines were carefully designed by Marshall University, to advance its commitment to sustainable energy as depicted in Figure 2. These turbines not only demonstrate the latest advancements in wind power but also provide students with the chance to conduct experiments, study performance characteristics, and gain invaluable insights into the mechanics of wind energy conversion. Additionally, the industrial lab features two state-of-the-art wind tunnels, where students can investigate the aerodynamics and the fluid dynamics of the wind turbines and their blades. These wind tunnels are essential tools for exploring the behavior of wind over different surfaces, assessing the efficiency of wind turbine blade design, and optimizing their performance.

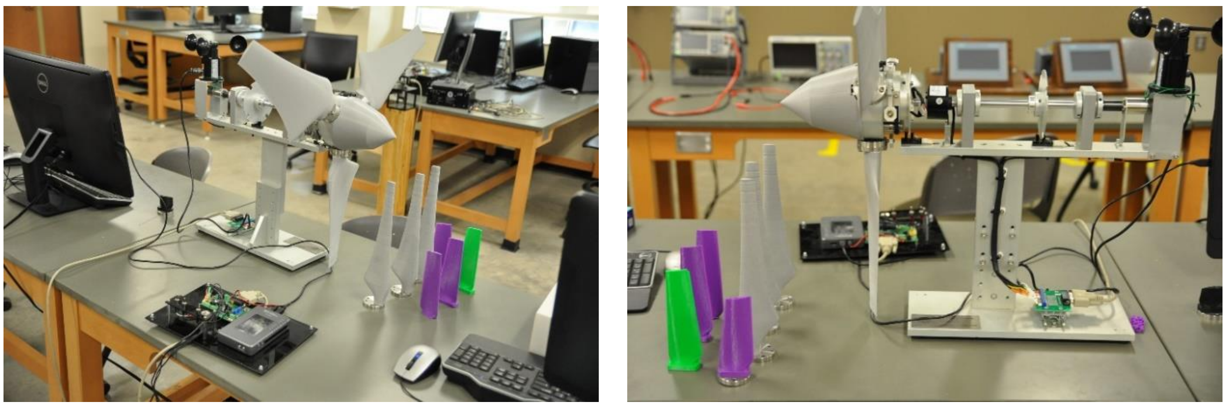

Figure 2: Illustration of Marshall University Wind Turbine Model, its control system, and custom-designed blades using 3D printers.

To support these practical laboratory experiments, the lab is fully equipped with advanced computers and essential software tools, including Matlab and LabVIEW. These resources empower students to analyze and process data from experiments, enhancing their ability to design and control renewable energy systems. A distinguishing feature of our lab is the custom designed LabView interfaces that control the wind turbines and wind tunnels. These interfaces offer students a user-friendly platform to interact with and monitor the equipment, facilitating real-time data collection and analysis. Our well-equipped engineering laboratories, with their focus on wind and solar energy, offer students a unique opportunity to explore the latest developments in the field. By combining theoretical knowledge with hands-on experimentation and the use of cutting-edge technology, we aim to prepare the next generation of engineers to meet the growing demand for sustainable energy solutions and drive positive change in our world.

3.1 Wind Turbine

The wind turbines contained in our program highlight Marshall University's commitment to cutting-edge teaching and research in the field of renewable energy. Custom-designed specifically for both undergraduate and graduate-level education and research, these turbines exemplify the innovation and practicality that are integral to our curriculum. Figure 3 and Figure 4 illustrate the components and the custom-design of Marshall University wind turbines. Wind turbines are designed to harness the power of the wind to generate electricity. They represent a clean and sustainable source of energy that is increasingly important to global efforts to combat climate change and reduce the reliance on fossil fuels. Theoretically, wind turbines start to generate electric energy at relatively low wind speeds, typically around 3 meters per second, and reach their maximum power generation potential at wind speeds ranging from 12 to 13 meters per second. This efficiency at optimum wind makes them a vital component of the transition to green energy.

A wind turbine consists of several key components, each playing a crucial role in its operation. The tower, a striking feature of the landscape, provides the necessary elevation to capture the wind's energy effectively. Balanced at the top of the tower is the rotor, which is the rotating core of the turbine. In turn, the rotor consists of several key parts, including the blades and the central hub to which they are attached. While turbines can vary in the number of blades they have, the three-blade rotor configuration is widely favored for its optimal efficiency and various advantages. These blades are designed to capture the kinetic energy of the wind. They are usually made to be lightweight yet robust and strong in the face of powerful changes in the wind. They are often hollow and constructed from composite materials that offer a perfect balance of strength and weight. With the evolving technology and engineering principles, modern turbines are designed with larger, more aerodynamic blades to maximize power production. These blades take the form of airfoils, much like the wings of an airplane, which helps them efficiently convert wind energy into rotational motion. Importantly, these blades are not flat but instead include a twist along their length, optimizing their performance and ensuring they can adapt to varying wind conditions.

One remarkable feature of wind turbines is their ability to adjust the angle of their blades. This movement is known as blade pitch, and it's a critical factor in optimizing energy capture. By changing the blade pitch, turbines can respond to changes in wind speed and direction, ensuring that they maintain peak efficiency and safety while operating in a wide range of environmental conditions. The wind turbines custom-designed by Marshall University include capabilities to experiment with custom-designed blades and optimize their functionality. Students are exposed to hands-on skills for harnessing the wind's power through a combination of advanced materials, aerodynamic design, and precise control.

One of the integral components within a wind turbine's intricate machinery is the generator, paired with the turbine shaft, which serves as the crucial link in the chain of the components that transforms the kinetic energy of the wind into usable electric energy. The process begins with the turbine's rotor, which captures the wind's force and transfers it to kinetic energy through the main shaft. However, the raw power harvested from the wind typically spins the main shaft at a relatively slow speed, often between 12 to 25 rotations per minute (rpm) in today's turbines. To convert this kinetic energy into electricity, the main shaft is connected to a generator, and it is the gearbox that plays a pivotal role in this process. Placed within the nacelle, the gearbox serves as an essential component of wind turbines, bridging the gap between the main shaft's relatively low rotational speed and the higher-speed operation required by the generator. For this reason, the end of the main shaft that connects to the generator is aptly named the high-speed shaft. The gearbox steps up the speed of the main shaft to match the generator's requirements.

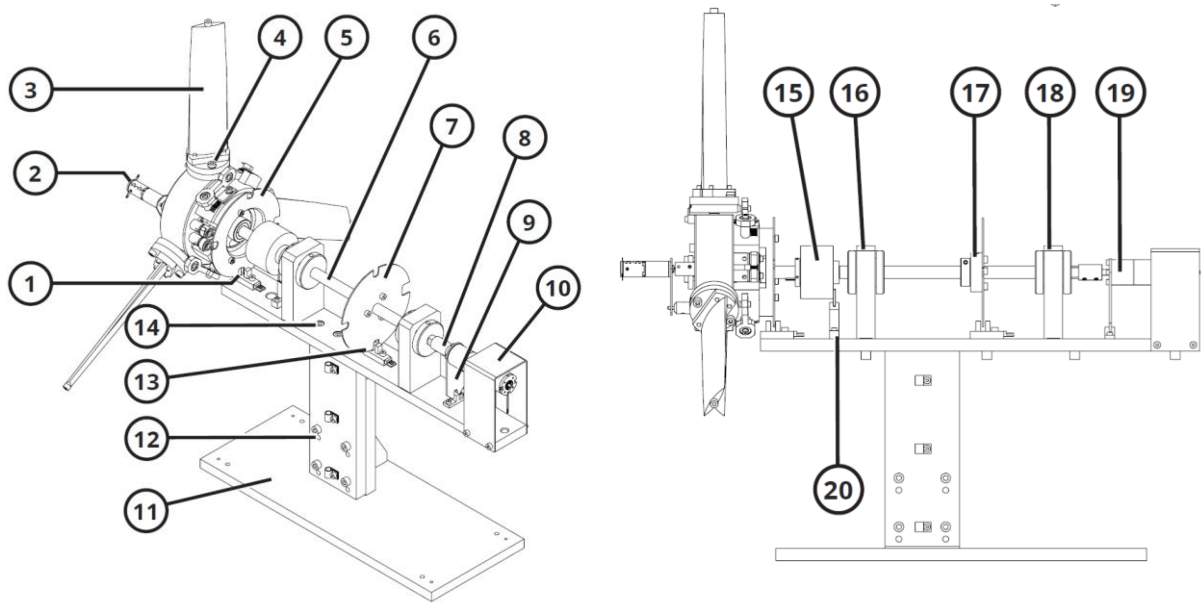

Figure 3: Components of MU Wind Turbine (Side View): (1) Photo interrupter for pitch, (2) Pitch motor, (3) Wind turbine blade, (4) Mounting plate for blade, (5) Timing disk for pitch measurement, (6) Low speed turbine shaft, (7) Timing disk for RPM measurement, (8) Generator coupler, (9) Torque-arm for generator, (10) Generator protection cover, (11) Base plate, (12) Wind turbine tower with multiple holes for height adjustment of hub, (13) Photo interrupter for RPM, (14) Mounting plate for turbine shaft, hub and sensors, (15) Slipring assembly, (16) Mount for shaft bearings, (17) Timing disk for RPM measurement, (18) Mount for shaft bearings, (19) Generator with integrated planetary gearbox, (20) Torque arm for slipring assembly.

To maximize power generation, wind turbines need to adapt to the changing direction of the wind so that the rotor always faces the wind. This adjustment is facilitated by the yaw motion, during which the nacelle and the rotor revolve around the tower's axis to maintain the optimal wind orientation. The generator itself plays a pivotal role in the energy conversion process. It transforms the mechanical energy derived from the rotor, which is harnessed from the wind's power, into electrical energy. The generator is structurally similar to an electric motor but with the opposite function. In wind turbine applications, the generator is of the induction type (asynchronous). In contrast, a synchronous generator necessitates a tightly controlled constant speed to maintain a consistent frequency, typically 50 or 60 Hz in most countries. The induction generator doesn't require such precise control of its speed. The wind turbine's rotor cannot rotate at a high speed. The gearbox increases the rotational speed of the main shaft to a level that can be effectively used by the generator. This process allows wind turbines to efficiently convert the wind's kinetic energy into a form of electricity that can be readily incorporated into the electrical grid.

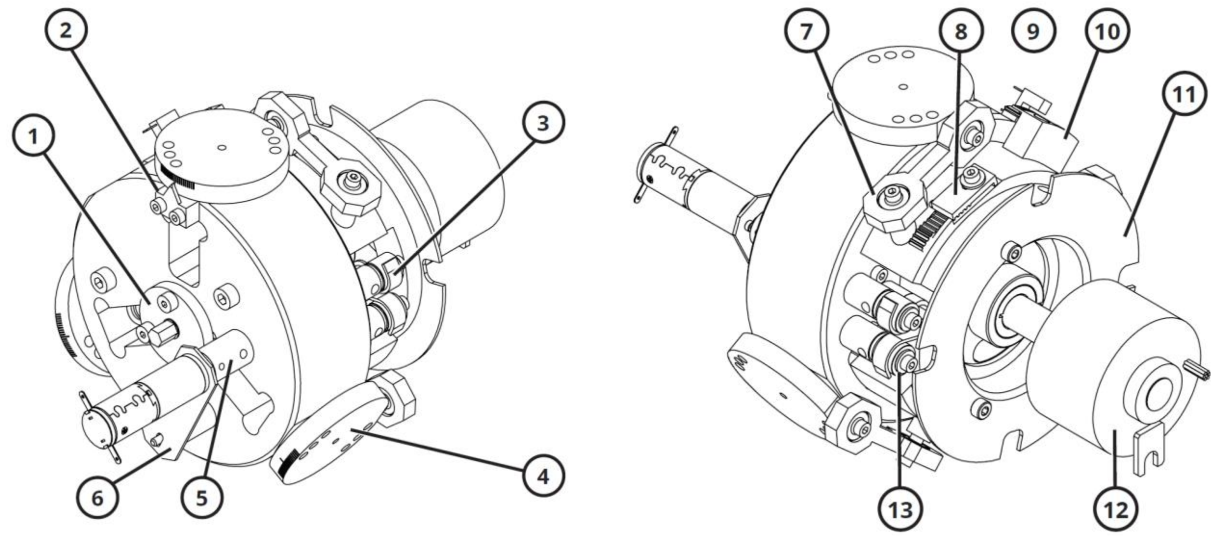

Figure 4: Components of MU Wind Turbine Generator (Side View): (1) Hex key adaptor to drive wind turbine with a motor, (2) Mechanical pitch indicator, (3) Pitch drive belt, (4) Mounting plate for blade, (5) Coupler for pitch motor, (6) Torque arm for pitch motor, (7) Pitch control arm, (8) Clamp to adjust tension on pitch drive belt, (9) (OPTIONAL) Photo interrupter for pitch, (10) (OPTIONAL) Sensor unit for pitch, (11) Timing disk for pitch measurement, (12) Slipring assembly, (13) Guide for pitch drive belt.

Therefore, the gearbox of a wind turbine is a critical component in the power conversion process due to the inherent variability of the wind itself. Wind energy is renewable and environmentally friendly, but it's also unpredictable and constantly changing. The wind speed and direction can fluctuate significantly over short periods. Thus, wind turbines must adapt to the continuous fluctuation of wind energy. This rapid adaptation can result in dynamic stresses on the gear teeth of the gearbox, causing fatigue and leading to the failure of the gearbox. The weight and size of the gearbox add to the structural demands of the turbine itself and can influence its overall stability.

3.2 Wind Tunnel

The AF100 subsonic wind tunnel, manufactured by TecQuipment and equipped with a cutting-edge Data Acquisition System (VDAS®), is a versatile tool for a wide range of wind generation and aerodynamic analysis applications (Figure 5). With its capabilities and precision, it is extensively integrated in research and education for both undergraduate and graduate students. The AF100 offers real-time data capture, monitoring, and display on a dedicated computer. This not only enhances the efficiency of experiments but also allows researchers and students to gain insights into the complex world of aerodynamics. The working section of the AF100 measures 305 mm x 305 mm x 600 mm in length, providing sufficient space for various experiments. It can generate air velocities ranging from 0 to 36 meters per second, ensuring that it covers a wide spectrum of aerodynamic conditions. This flexibility makes it an ideal choice for a diverse range of research projects and educational demonstrations. Researchers and students can conduct experiments to analyze the aerodynamics of wind turbine blades, which is vital for optimizing their efficiency and performance. This knowledge is instrumental in the ongoing development of renewable energy solutions. Furthermore, the AF100 has proven to be an excellent resource for investigating core aerodynamic principles. For instance, it is frequently used to study the influence of aspect ratio on aerofoil performance. This exploration helps researchers and students understand how the shape and dimensions of aerofoils impact their lift and drag characteristics. Another application of the AF100 involves the measurement of lift, drag, and pitching moment on three-dimensional aerofoils. This is crucial for designing and fine-tuning various aerospace and mechanical systems, where the precise control of aerodynamic forces is of paramount importance.

In a classroom setting, the AF100 enables engaging demonstrations on the performance of an aerofoil with a flap. Students can investigate the size and shape of custom-designed blades. This hands-on experience enhances their understanding of complex aerodynamic principles and instills a deeper appreciation for the intricacies of wind energy technologies. The AF100 subsonic wind tunnel is not merely a piece of equipment; it is a gateway to a world of research, innovation, and education. Its capabilities span from the analysis of wind turbine blades to fundamental aerodynamic studies, making it an invaluable asset for the exploration and advancement of aerospace, mechanical engineering, and renewable energy. As students and researchers continue to push the boundaries of aerodynamics, the AF100 plays a pivotal role in turning their ideas and theories into tangible results and solutions.

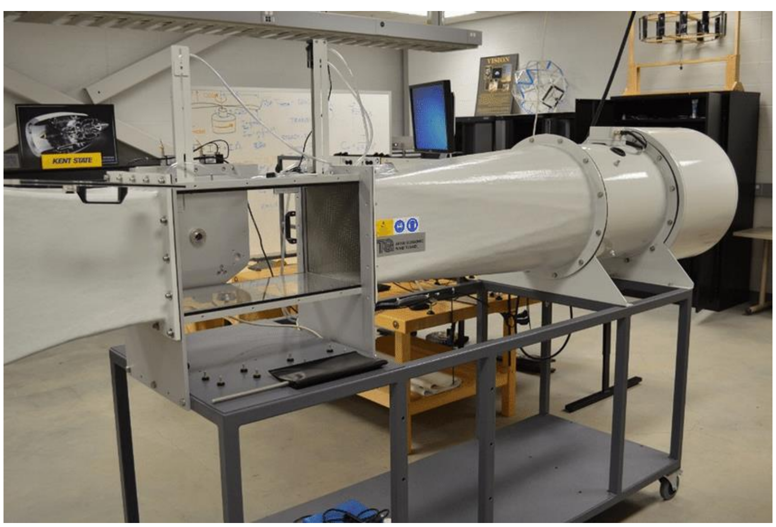

Figure 5: Illustration of AF100 Wind Tunnel.

Within this advanced laboratory, there's an array of specialized instruments and equipment, including waveform generators, spectrum analyzers, and oscilloscopes. These instruments are pivotal in various aspects of research and experimentation, and their applications extend far beyond the immediate scope of the lab. Waveform generators are versatile devices that produce a wide range of electrical waveforms, making them indispensable tools for engineering and scientific investigations. They allow researchers and students to generate precise waveforms for a myriad of purposes, from testing electronic components to simulating real-world signals. In the context of wind energy research, waveform generators can be used to simulate electrical output signals from wind turbines, helping to understand how the electrical systems respond to varying wind conditions. Spectrum analyzers are vital for characterizing the frequency domain of signals. They are essential in studying and troubleshooting the various frequencies associated with wind turbine operation. This information is invaluable for understanding and mitigating noise issues, which can be a significant barrier to the widespread adoption of wind energy. Oscilloscopes, with their ability to visualize electrical waveforms in real time, offer an essential tool for monitoring and diagnosing electrical and mechanical systems. One of the prominent challenges in the wind energy sector is addressing the issue of wind turbine noise. Noise pollution from wind turbines can be a significant hindrance to their widespread acceptance. To tackle this issue, researchers and engineers need to understand the mechanisms that give rise to wind turbine noise. To this end, an innovative approach involves deploying an array of horizontal microphones positioned near the rotating blades. By using these microphones to capture and measure the distribution of noise sources along the individual blades, researchers can gain critical insights into the specific locations and characteristics of noise generation. This information is instrumental in developing strategies to mitigate wind turbine noise, thus making wind energy more environmentally friendly and socially acceptable.

3.3 Wind Turbine Blades

Wind turbines are designed to harness the power of the wind, but they present unique control challenges due to the uncontrollable nature of the wind. They effectively convert wind energy into electricity through the utilization of aerodynamic principles. The core of a wind turbine's power generation lies in its rotor blades, which function much like the wings of an airplane or the rotor blades of a helicopter. When the wind flows across the surface of these blades, it creates a pressure differential between the two sides. This difference in air pressure generates both lift and drag forces that enable an aircraft to take flight. However, the force of the lift surpasses that of drag, setting the rotor into motion and causing it to spin. The rotor's rotation is intimately connected to a generator, either directly or through a system of shafts and gears of the gearbox. The gearbox serves to increase the rotational speed of the rotor to a level that allows for the efficient operation of a relatively smaller generator. Modern wind turbines are equipped with pitch control systems, allowing the adjustment of the blade pitch angle. This adaptation ensures that the power output from the turbine is optimized for the prevailing wind conditions, all while protecting the generator and the mechanical components of the blades, tower, and rotor shaft from overloading. The mechanism for fine-tuning power output to wind speed is based on a turbine's performance curve, often referred to as a power curve. This curve serves as a power schedule and is employed by a computer within the turbine's control system. The computer uses this curve, in conjunction with real-time wind speed data, to make continuous adjustments to various components, ensuring that the turbine operates at peak efficiency without exceeding its mechanical limits.

However, before these finely tuned blades can be put into action, they need to be manufactured. Marshall University's 3D Printing Lab plays a crucial role in this process, equipped with three advanced 3D printers as depicted in Figure 6. The FabPro 1000 3D Printer stands out for its ability to produce high-quality parts rapidly, reducing production time from days to hours. The MakerBot Replicator 3D Printer is a reliable and user-friendly device that comes with standardized features, simplifying the 3D printing process. The Stratasys F120, boasting user-friendly controls and remote self-monitoring capabilities, offers high levels of reliability and repeatability. These state-of-the-art 3D printers are integral in the production of wind turbine blades, allowing for the creation of precisely engineered, aerodynamically optimized components that maximize energy conversion and overall efficiency. By combining advanced control systems and cutting-edge manufacturing technology, we continue to advance the field of wind energy, making it a more dependable and sustainable source of renewable power.

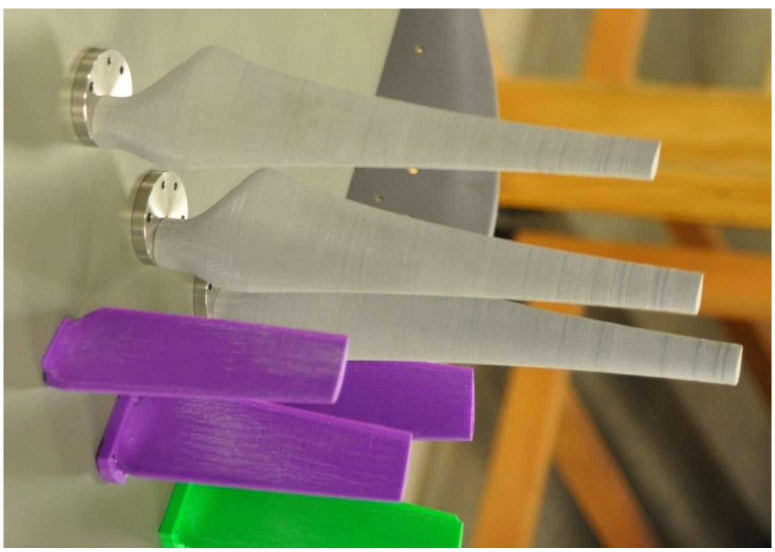

Figure 6: Illustration of Custom Designed Wind Turbine Blades

3.4 Wind Turbine LabView Interface

The curriculum offers an array of practical applications that not only enrich the learning experience of undergraduate and graduate students but also empower them with invaluable skills. At its core, this curriculum is designed to expose students to the LabView custom-designed interfaces for harnessing wind energy through the use of wind turbines. One of the standout features of this curriculum is the utilization of LabView, a software platform that provides students with a powerful toolset for developing and running programs. LabView's versatility and user-friendly interface make it an ideal choice for students to investigate research projects related to green energy. LabView has an array of functionalities, including built-in automated test systems, rapid data analysis tools, configurable and interactive display elements, as well as drivers for automating various instruments and data acquisition hardware. These features collectively offer students the opportunity to engage in hands-on experimentation and data analysis.

The hardware setup used in the laboratory activities complements the software's capabilities, allowing students to design, validate, and fine-tune various components of a comprehensive wind energy system. This practical approach not only teaches theoretical knowledge but also equips students with the skills needed to work in real-world applications. Through this approach, students gain an understanding of the complexities involved in harnessing wind energy efficiently. The custom designed LabView interfaces serve as a bridge between theory and practice, enabling students to monitor and control different aspects of wind turbines used in the laboratory (Figure 7). They provide real-time data and visual feedback, which is indispensable for optimizing the performance of wind turbines. This hands-on experience enhances students' problem-solving abilities and critical thinking skills, making them better equipped to tackle the challenges faced in the field of renewable energy. Through the integration of LabView and custom-designed interfaces, students gain a deep understanding of wind energy systems, which is essential in our ongoing quest for sustainable and eco-friendly energy sources. This comprehensive and hands-on approach to learning sets the stage for a brighter, more sustainable future of renewable energy.

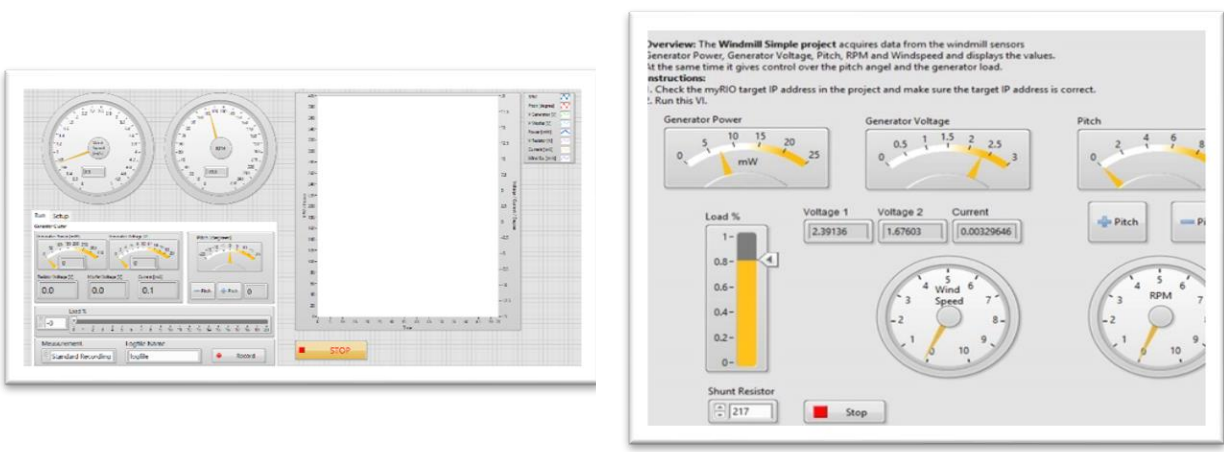

Figure 7: Illustration of Wind Turbine LabView Control Interface Panels Examples

The curriculum provides the specific needs and development stages of engineering students, tailoring the learning experience for both first- and second-year students as well as senior-year students and graduate students. For the first- and second-year students, the emphasis is on providing a solid foundation in wind turbine technology and energy generation. Students will engage with custom designed LabView applications that cover all facets of wind turbine systems and energy production. This hands-on approach not only introduces them to the practical aspects of renewable energy but also instills a strong understanding of the fundamental principles that underpin these technologies. They will have the opportunity to work with the LabView software, gaining proficiency in its usage and developing practical skills in energy monitoring and control.

As students progress to their senior year and graduate studies, the curriculum takes on a more advanced dimension. Here, the focus shifts towards equipping students with the expertise to write their own LabView applications. This not only encourages self-sufficiency in programming but also opens the door to more complex and innovative wind energy applications. Seniors and graduate students are not just consumers of existing technology but are actively engaged in research and development. Moreover, students are encouraged to explore the most intricate and cutting-edge wind energy applications. They are urged to think beyond the confines of traditional wind turbines and to consider alternative methods and integrations. This holistic approach sparks their creativity and innovation, inviting them to imagine and design new ways to harness wind energy efficiently and sustainably. Additionally, the curriculum promotes synergies between wind energy and other green energy mechanisms, encouraging students to explore hybrid systems that combine wind, solar, or other renewable sources to create comprehensive and eco-friendly energy solutions. This comprehensive educational journey not only equips students with the knowledge and skills they need to excel in the field of renewable energy but also fosters a spirit of innovation and sustainability.

IV. Curriculum Design Strategies

The curriculum is designed to offer a comprehensive educational experience that blends traditional classroom instruction with practical, hands-on skills. It leverages the already robust engineering laboratory infrastructure housed within the College of Computer Science and Engineering. This integrated approach ensures that students not only acquire theoretical knowledge but also gain valuable experiential learning. Within the college’s facilities, students have access to a wide array of laboratories tailored to support interdisciplinary engineering courses. These laboratories are equipped with cutting-edge technology and resources, creating an ideal environment for hands-on skill development. Here are some of the key laboratories that play a pivotal role in enriching the educational journey:

- Industrial Control Laboratory: This laboratory is a hub for exploring renewable energy solutions. It houses state-of-the-art wind and solar instrumentation, complemented by a fleet of computers and licensed software like Matlab and LabView. This robust setup empowers students to design, simulate, and analyze various control systems for renewable energy applications, preparing them for real-world challenges in the field.
- 3D Printing Laboratory: With a focus on design innovation, this laboratory equips students with the tools and knowledge to turn their ideas into tangible prototypes. The availability of

cutting-edge 3D printing technology enables students to bring their design concepts to life, fostering creativity and practical problem-solving skills.
- Electric Power & Energy Conversion Laboratory: This laboratory caters to the intricate world of power electronics, power systems, renewable energy systems, and smart grid technology. Here, students engage in hands-on activities that explore the efficient generation, conversion, and distribution of electrical power, preparing them for careers in the ever-evolving energy sector.
- Wireless Communications Systems Laboratory: With a focus on modern communication technologies, this laboratory provides an arena for students to conduct extensive experiments. They delve into the realms of wireless communications, cellular networks, and digital signal processing. These hands-on experiences not only enhance their understanding of communication systems but also drive innovative research in this field.
- Cyber Training Center: In an age where cybersecurity is paramount, this center serves as a training ground for the cybersecurity professionals of tomorrow. Students receive practical, real-world experience in cybersecurity, developing the skills necessary to address the evolving challenges of the digital landscape and ensuring the security of systems and data.

In the process of designing this curriculum, careful consideration has been given to creating an adaptable and evolving framework. This adaptability is crucial to ensure that the curriculum remains aligned with the available resources, faculty expertise, and the evolving needs of regional industries. This forward-thinking approach is anchored in several strategies, including:

- Regular curriculum reviews and updates to incorporate the latest technological advancements.
- Collaboration with industry partners to identify emerging trends and skills in demand.
- Faculty development programs to ensure instructors stay current with the evolving field of engineering.
- Flexibility in course offerings to accommodate emerging disciplines and specialties in engineering.

These strategies collectively ensure that students are not only well-prepared for the challenges of today but also positioned to be agile problem-solvers and innovators in the engineering landscape of tomorrow. The curriculum's adaptability and emphasis on practical learning make it a dynamic platform for nurturing the next generation of engineers who will drive technological progress and meet the needs of their communities and industries.

4.1 Academic Strategies

The academic strategies focused on the means to deliver knowledge that will allow graduate students to work on projects and areas that will enhance and promote green energy. The academic strategies included the following:

- Modular Design: The curriculum's foundation is rooted in modular design principles. It was developed by aligning educational and training goals with existing resources such as faculty expertise, classroom and laboratory facilities, and core curriculum content in power and energy across multiple engineering disciplines. This approach ensures that students benefit from a well-structured, coherent curriculum that efficiently utilizes available resources.

- Hands-on Skills: A key objective during the curriculum's development was to provide students, both at the undergraduate and graduate levels, with practical, hands-on skills. The emphasis on tangible, real-world applications led to the establishment of a unique infrastructure, a rare resource found at only a handful of institutions. These hands-on experiences equip students with the expertise and confidence needed to excel in green energy projects and industries.
- Flexibility: The curriculum is inherently flexible, mirroring the flexibility present in the resources created throughout its development. This adaptability allows for continuous improvement, adaptation to evolving technologies, and the incorporation of emerging industry trends. The curriculum can remain dynamic, responding to the ever-changing landscape of green energy.
- Interdisciplinary Coverage: One of the strengths of this curriculum is its breadth, covering various disciplines and courses related to power and energy. By encompassing a wide range of subjects, students are well-prepared for diverse career paths in the green energy sector. This comprehensive approach also encourages interdisciplinary collaboration and the cross-pollination of ideas and solutions.
- Multi-Level Learning: The curriculum caters to students at various stages of their academic journey, offering exposure to renewable energy concepts at multiple levels. For instance, freshman students engage in scalable renewable energy experiments that go beyond textbook knowledge, enabling them to comprehend the practicalities, advantages, and challenges of green energy. This multi-level approach fosters a deeper understanding and appreciation of renewable energy's nuances.
- Expandability to Future Innovation: A forward-thinking aspect of this curriculum is its readiness to accommodate future innovations in the field of renewable energy. The infrastructure and resources created are adaptable, allowing for the extension of hands-on learning and research activities into emerging areas, such as wind and solar energy forms. This future-oriented approach keeps the curriculum relevant and aligned with the evolving landscape of green energy.

4.2 Research Strategies

Our strategies for learning from research are based on research projects that enable students to enhance their learning skills and expose them to the latest advances in green energy. The research strategies included the following:

- Interdisciplinary Research: The research component of this curriculum encourages interaction between graduate and undergraduate students, facilitating an exchange of knowledge and skills. This approach creates a dynamic learning environment that exposes students to the latest advances in green energy, fostering collaboration between students with different disciplinary backgrounds.

- Open-Ended Research Projects: The curriculum promotes research at all levels, presenting students with open-ended projects that require them to acquire knowledge and apply it through modular research activities. Students are tasked with developing research projects that have practical applications and must be completed within a specified time frame, mimicking real-world constraints, including time and budget limitations.
- Graduate Student Projects: Graduate students are encouraged to design projects that align with the rigor of their specific courses and make full use of the resources available in dedicated laboratories. This approach ensures that research at the graduate level is comprehensive, in-depth, and relevant to the field of green energy.
- Faculty Collaboration: The curriculum's research resources and laboratories are made available to faculty members from various engineering disciplines, fostering interdisciplinary collaboration and enabling the design of relevant courses and research materials. This collaboration ensures that research activities remain at the cutting edge of the field and can adapt to emerging trends and technologies.

The academic and research strategies embedded in this curriculum are designed to provide students with a well-rounded, adaptable, and future-oriented educational experience. By focusing on modular design, hands-on skills, flexibility, interdisciplinary coverage, multi-level learning, and research innovation, the curriculum equips students with the knowledge and skills they need to excel in the dynamic field of green energy and make meaningful contributions to the ongoing transition to sustainable energy sources.

4.3 Industry Partnership Strategies

To further entrench industry involvement in the wind and solar energy proposed curriculum, it is our vision that a very dynamic and symbiotic relationship will be established with the renewable energy sector. This is an important link that will keep the curriculum fresh and equip the students to be better able to serve the changing needs of the industry. We will implement the following strategies to further enhance collaborations with industry:

- Form panels consisting of experts in the wind and solar industry in the field of engineering, project management, sustainability, and policy advocacy. The curriculum will be guided in a manner reflecting the present challenges of technologies witnessed in the industry.
- Plan for a set of interactive sessions which would include the conduct of industry-led workshops, guest lectures, and virtual reality tours of energy facilities. All these engagements will bring the students and faculty up to speed with the current industry as well as develop practical understanding of renewable energy systems.
- Create internships and co-op programs in partnership with industry Structures that will allow students to work on real-world projects with respective industry partners.
- Involve industry professionals in the design of curriculum by focusing on applied learning opportunity integration from projects that are sourced directly from industry challenges.
- Align the curriculum of the professional industry recognitions to empower the student credentials.

- Develop research collaboration projects between students, faculty, and industry players. The projects may be directed at solving the specific problems of industry or developing new technologies.
- Encourage continuous learning and professional engagements that will foster a spirit of continuous learning and professional engagements through on-line forums, digital libraries, and participation in industry events.
- Design program outcomes with industry stakeholders for direct inputs to improve the curriculum and define metrics to measure its effectiveness against the emerging needs of the industry.

These strategies assure strong linkage of academic learning with the practical projects from the wind and solar energy industries, which will make our graduates not only well-informed but also valuable to employers in the renewable energy industry.

V. Curriculum Assessment and Improvement

We designed this curriculum to incorporate not only learning but also capabilities of the resources assessment and improvement. For the assessment of resources, faculty and students will be encouraged to provide input to improve the content of the courses, hands-on activities, and learning materials. The evaluation will include methods and criteria to measure the curriculum's effectiveness in providing necessary materials and equipment, thereby enhancing educational outcomes, and fostering innovation. This process will also support the development of learning materials and hands-on activities essential for student engagement and skill acquisition. Our assessment approach encompasses the following strategies:

- Resource Assessment and Continuous Improvement in Curriculum Design: The curriculum's foundation is not just static; it's designed with a forward-looking perspective that encompasses both learning and resource assessment. This approach is intended to ensure that the curriculum remains not only relevant but also at the forefront of educational innovation.
- Faculty and Student Feedback Loop: The curriculum promotes a symbiotic relationship between faculty and students, encouraging them to actively participate in the ongoing assessment and improvement of the curriculum. Faculty members and students alike are urged to provide valuable feedback on various aspects, including the content of courses, the effectiveness of hands-on activities, and the quality of learning materials. This two-way feedback loop empowers those directly involved in the educational process to shape and enhance the curriculum continually.
- Assessment Tools and Rubrics: To facilitate this assessment process, the curriculum includes well-defined assessment tools and rubrics. These instruments allow for a systematic and objective evaluation of the curriculum's resources and capabilities. They help identify areas that need improvement and provide clear guidelines for measuring the effectiveness of educational materials and activities.
- Resource Enhancement: As green energy technologies advance and expand, the curriculum is prepared to evolve in tandem. The infrastructure is not fixed but designed with flexibility in mind. It will be periodically updated to ensure it remains aligned with the latest

developments in the field of green energy. This commitment to staying up to date reflects the curriculum's dedication to providing students with state-of-the-art hands-on training experiences.

- Research Facilities Expansion: The curriculum isn't just focused on undergraduate education; it also encourages the engagement of graduate students with the latest research topics. To support this, research facilities will be expanded to provide a dynamic environment for graduate-level research projects. This approach ensures that students at all academic levels have access to cutting-edge resources and opportunities to contribute to the advancement of green energy technologies.
- Industry Collaboration: An integral part of the improvement strategy involves collaboration with industry partners. The curriculum is designed to stay responsive to the real-world needs of the industry. By actively seeking input from industry experts, the curriculum can be adapted to address emerging trends and requirements, ensuring that graduates are well-prepared for the job market.
- Continuous Feedback Loop Diagram: The diagram provided illustrates the systematic approach to updating and improving the curriculum. It represents an ongoing cycle where inputs from both faculty and students are gathered, assessed, and used to make enhancements. The curriculum's adaptability and responsiveness to the evolving landscape of green energy are core principles that guide its continuous improvement.

The curriculum’s commitment to resource assessment and continuous improvement sets it apart as a forward-thinking and adaptable educational framework. By actively involving faculty, students, and industry partners, and incorporating assessment tools and rubrics, it ensures that the learning experience remains of the highest quality and aligned with the ever-changing field of green energy. This commitment to excellence and continuous refinement is key to preparing students to excel in the dynamic and innovative world of sustainable energy solutions. As green energy advances and its application expands, we will update the infrastructure to provide laboratory capabilities that will enrich the learning experience of students with state-of-the-art hands-on skills for training. We will also expand the research facilities to engage graduate students with recent topics in research. We will follow the approach of learning input from our industry partners.

VI. Conclusion

This curriculum has been a long process, and an important goal is to create educational programs and kerning skills for renewable energy at Marshall University. The curriculum has allowed for the design of several courses and learning, training, and hands-on skills that are necessary for educating and training the next generation of engineers to work and advance renewable energy and transition and expandability in West Virginia. Through this curriculum, we plan to build on this curriculum to generate learning, hands-on skills to retrain for the existing engineers and workforce. We also plan to encourage and design learning modules that can be included in summer learning for teachers and students in middle and high schools. We plan to design learning and demonstration materials to encourage citizens, teachers, educators, and politicians on the importance of renewable energy in west Virginia and the risks and non-renewable energy on human health and water resources, and the environment and wildlife. We plan to promote concerns about the effects of global warming on West Virginia. The impact of the curriculum goes beyond just educating new engineers. It also has the potential to facilitate the retraining of the existing workforce. With the evolution of the energy sector towards renewables, many professionals may need to acquire new skills. This curriculum provides a framework for continuing education and skills upgrading, ensuring that the local workforce remains competitive in a changing energy landscape. The curriculum also emphasizes the importance of sustainability and its impact on human health, water resources, the environment, and wildlife. It intends to create learning and demonstration materials that can be used to educate citizens, teachers, policymakers, and politicians. Raising awareness about the risks associated with non-renewable energy sources and the benefit of renewable energy encourages a shift toward more sustainable and environmentally responsible practices. Additionally, the curriculum seeks to promote awareness about the broader implications of global warming. West Virginia, like many regions, is not immune to the effects of climate change. The curriculum aims to foster concerns about the consequences of global warming within the local context and encourage action at the community and policy levels.

Bibliography

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