Vehicle-Based Electric Power Generation: Advancements in Hardware Interface Development

Prince Winston.D[1], Shafiq Ahamed[2]. K, kausik[2] . O.B, Veerendra Sevak .P[2], HariRajan. K[2], Santhosh Sahaya Raj[2], Vignesh.V.K[3] , Kavitha.S[4]

[1]Professor, Department of Electrical and Electronics Engineering, Kamaraj College of Engineering and Technology, Virudhunagar, Tamil Nadu, India.

[2,3]Department of Mechanical Engineering, Kamaraj College of Engineering and Technology, Virudhunagar, Tamil Nadu, India.

[4]Assistant Professor, Department of Electrical and Electronics Engineering, Kamaraj College of Engineering and Technology, Virudhunagar, Tamil Nadu, India.

Abstract: This paper presents a comprehensive study on the integration of wind energy with electric vehicle (EV) charging infrastructure to promote sustainable transportation practices and renewable energy utilization. In this paper, we focus on the seamless integration of a horizontal-axis wind turbine (HAWT) system with EV charging, aiming to harness locally generated wind energy for charging EV batteries. The methodology involves designing, implementing, and evaluating the integrated system, considering factors such as wind turbine design, mechanical and electrical integration, charging infrastructure setup, and system optimization. The working of the paper involves the efficient conversion of wind energy into electrical power, which is directed to the EV charging infrastructure for charging EVs directly user-friendly interfaces empower EV owners to monitor and control the charging process. This paper contributes to the growing body of research on renewable energy integration and sustainable mobility, offering insights and recommendations for future initiatives in this field.

I. INTRODUCTION

An important field for study and development to meet the growing issues of environmental sustainability and energy security is the integration of renewable energy sources with mechanical systems. Against this backdrop, the goal of this article is to investigate the possibilities of wind power and electric cars (EVs) by creating a wind turbine system [1-3]. To build a sustainable solution for clean transportation and make use of the parked idle time of the EV, the study proposes to leverage the mechanical principles of a Horizontal axis wind turbine (HAWT) and link its power-generating capabilities with the propulsion system of EVs [4,5]. The assumption underlying this study is that to lessen the negative effects of fossil fuels, a swift transition to sustainable energy methods is required.

The utilization of wind energy, a plentiful natural resource, offers a viable solution to this problem. The article proposes the construction of a 2kW HAWT system with a focus on efficiency, reliability, and scalability, specifically for residential applications, in line with this goal. The study attempts to maximize energy capture and conversion while guaranteeing durability and safety by carefully developing and optimizing the mechanical components of the turbine, including the gear system and rotor blades. This wind turbine system's utility is further increased by its connection with electric vehicles (EVs), which makes it possible to directly charge car batteries with clean, renewable energy.

The wireless charging system based on solar systems employed is simulated using Ansoft or Matlab software [6-8]. The study of hybrid charging infrastructure, incorporating a reconfigurable battery and PV system, alongside PV energy forecasts integrated into the control system, enhances the self-sufficiency of the hybrid system[9].

The goal of this interdisciplinary research at the nexus of sustainable mobility, renewable energy technology, and mechanical engineering is to advance creative solutions that support energy independence and environmental stewardship. Through clarifying the technical details and useful uses of the suggested wind turbine, EV integration, this article seeks to stimulate more investigation, creation, and uptake of sustainable energy solutions in the interest of a more environmentally friendly and sustainable future.

II. HORIZONTAL AXIS WIND TURBINES (HAWTS)

Horizontal-axis wind turbines (HAWTs) are pivotal in the paper's objective of integrating wind energy with electric vehicle (EV) charging infrastructure. Known for their high efficiency in converting wind energy into mechanical power, HAWTs boast optimal blade orientation relative to wind direction. This efficiency maximizes power output in wind-powered systems, including the one in this paper. HAWTs vary in size, from small-scale residential turbines to large utility-scale installations, offering flexibility in design and deployment. Their scalability renders HAWTs suitable for diverse applications, such as integration with EV charging infrastructure.

Designed to capture wind energy efficiently, even in turbulent conditions, HAWTs ensure maximum utilization of available wind resources, providing consistent and reliable power generation for charging EVs using renewable energy. They offer a cost-effective solution compared to alternative technologies, with standardized components and established manufacturing processes contributing to lower upfront costs and improved system economics. Moreover, HAWTs' compatibility with existing grid-connected systems makes them well-suited for integration with EV charging infrastructure, aligning with the promotion of sustainable transportation practices through renewable energy utilization.

III. EVS AND SUSTAINABLE TRANSPORTATION

Electric vehicles (EVs) are instrumental in advancing sustainable transportation, aligning with global efforts to reduce carbon emissions and fossil fuel dependency. In this paper, EVs serve as a cornerstone for sustainable mobility, offering advantages like lower emissions, quieter operation, and reduced fuel reliance. Powered by rechargeable batteries, EVs improve air quality and reduce noise pollution in urban areas. Advances in battery technology and charging infrastructure enhance the appeal of EVs for consumers and policymakers. Integrating EVs with renewable energy sources like wind power presents an opportunity to further enhance their environmental benefits. Wind-powered EV charging systems offer cost savings, energy efficiency, and environmental sustainability. By harnessing wind resources, these systems enable clean energy charging regardless of grid availability or electricity prices. Additionally, wind-powered charging stations can serve as educational tools, raising awareness about renewable energy and sustainable transportation. Overall, EVs are crucial components of sustainable transportation, offering environmental, economic, and societal benefits. Through EV integration with renewable energy sources, this paper aims to showcase the feasibility and effectiveness of clean mobility solutions, paving the way towards a more sustainable and resilient transportation future.

IV. DESIGN CREATION & ANALYSIS

In this paper, we designed a 2kW windmill using SolidWorks, aiming to contribute to sustainable energy solutions. The design features a sturdy tower to support the rotor and generator, optimized for efficient energy conversion. The rotor blades are carefully designed to capture maximum wind energy while ensuring structural integrity. The generator is positioned to harness the rotational energy from the rotor, converting it into electrical power. Overall, our SolidWorks design integrates functionality with aesthetics, demonstrating a practical and visually appealing solution for renewable energy generation. The design of the turbine components are as shown in Figure 1.

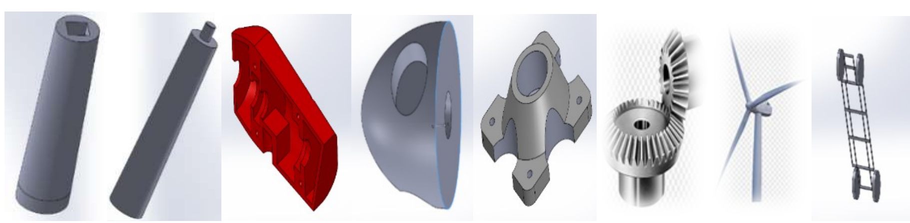


Figure 1. Wind turbine components

Table 1: Wind Turbine Specifications

Specification	Value	Specification	Value
Rated Power	2 kW	Number of Blades	3
Rotor Diameter	4 meters	Blade Material	Fiberglass
Swept Area	12.57 square meters	Tower Height	10 meters
Cut-in Wind Speed	3 m/s	Tower Material	Steel
Rated Wind Speed	10 m/s	Generator Type	Permanent Magnet
Cut-out Wind Speed	20 m/s	Generator Efficiency	90%
Rotor Type	Horizontal Axis	Controller Type	PWM

Specification	Value
Battery Type	Lead-Acid
Battery Capacity	24V, 200 Ah
Inverter Type	Grid-Tie
Grid Connection	Single Phase, 230VAC
Warranty	5 years

Table 2. Spiral Bevel Gear Specifications

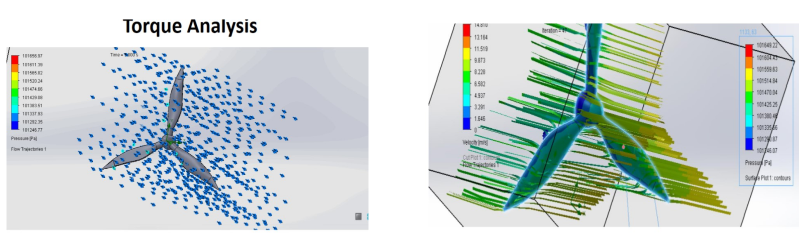
Parameter	Value
Gear Type	Spiral Bevel Gear
Number of Teeth	20
Module	2 mm
Pressure Angle	20 degrees
Pitch Diameter	40 mm
Face Width	10 mm
Helix Angle	30 degrees
Material	Steel
Tooth Thickness	4 mm
Gear Ratio	1:1

V. DESIGN AND OPTIMIZATION OF WIND TURBINE SYSTEM

The design and optimization of the wind turbine system are crucial for performance, efficiency, and reliability. It involves analyzing power output targets, site conditions, and integration with EV charging infrastructure. Rotor blades are designed to capture wind energy efficiently, while the gearbox converts rotor motion into suitable rotation for power generation. Gear ratios are carefully selected for system efficiency, ensuring reliable operation over the turbine's lifespan. Unlike conventional turbines, our system utilizes the EV motor as a generator, converting wind energy into electrical power. Table 1 and Table 2 lists the hardware specifications considered while designing.

The coupler facilitates seamless transmission of rotational motion from the wind turbine system to the EV charging infrastructure, optimizing performance by efficiently converting mechanical energy into electrical energy for charging EV batteries. Its design and selection cater to specific requirements like torque transmission and mechanical durability, with a universal coupler chosen for flexibility and cost-effectiveness. This pivotal component integrates wind energy into clean power for sustainable transportation, ensuring reliable coupling mechanisms and operation.

The design process utilizes advanced modeling and simulation tools to assess wind turbine performance under various conditions. Torque analysis and computational fluid dynamics play critical roles in assessing and optimizing the performance, efficiency, and reliability of wind turbines. Torque analysis helps ensure mechanical robustness, while CFD allows for the optimization of aerodynamic performance, ultimately contributing to the overall effectiveness of wind energy conversion. The proposed system is analyzed and it is shown in Figure 2.



(a) (b)

Figure 2. a) Torque analysis b) Computational Fluid Dynamics

6. IOT INTEGRATION

The integration of IoT technology with the wind turbine-EV charging system enhances its capabilities by enabling remote monitoring and control. In this section, the implementation of IoT using Arduino microcontrollers to gather real-time data from the wind turbine system and send it to a centralized monitoring application. Arduino microcontrollers are the backbone of the IoT infrastructure, offering the necessary hardware and software features for data acquisition, processing, and communication. By connecting sensors and actuators to Arduino boards, we can capture various parameters like wind speed, turbine rotation, and battery voltage.

For data acquisition and processing, sensors are strategically placed within the wind turbine system. For example, an anemometer measures wind speed, while a rotational sensor tracks the turbine's rotation speed. Arduino boards collect sensor data at set intervals and analyze it using programmed algorithms to derive meaningful insights.

In terms of communication protocol, Arduino boards come equipped with communication modules such as Wi-Fi or GSM. These modules facilitate data transmission to a remote server or cloud platform. To exchange data between Arduino devices and the central monitoring application, we utilize standard communication protocols like MQTT (Message Queuing Telemetry Transport) or HTTP (Hypertext Transfer Protocol).

VII. APPLICATION FOR PROPOSED SYSTEM

Built with Flutter, the monitoring app offers a user-friendly interface for seamless real-time tracking of wind turbine-EV charging system data on both iOS and Android devices. Users easily access comprehensive insights through an intuitive dashboard layout, displaying key metrics like wind speed, turbine rotation, power output, and battery status. Historical data analysis allows for trend analysis in energy generation, consumption, and efficiency, aiding performance optimization. Additionally, timely alerts ensure swift intervention for abnormal system behavior or critical events like low battery levels, enhancing overall system reliability. The app also provides remote control functionality, empowering users to adjust charging settings, activate safety mechanisms, or initiate maintenance routines as needed, thus enhancing operational flexibility. Leveraging Flutter's UI components and libraries, alongside the hot reload feature, ensures a smooth user experience. Backend services like Firebase or AWS handle data management efficiently. The front end of the application developed is as shown in Figure 3.

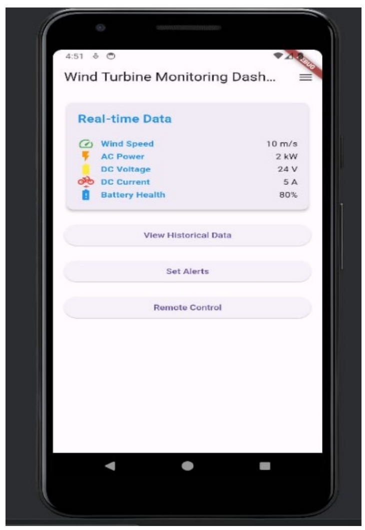


Figure 3. Application development for the proposed system.

VIII. CONCLUSION

In conclusion, the paper’s integration of a wind turbine with an electric vehicle (EV) charging system represents a leap toward sustainable transportation and renewable energy utilization. Through careful design and optimization of mechanical and electrical components, the paper has demonstrated the feasibility and effectiveness of harnessing locally generated wind energy to power EVs, thereby reducing carbon emissions and promoting energy independence.

By seamlessly integrating wind-powered EV charging infrastructure with user-friendly interfaces, the paper fosters user engagement and empowers EV owners to participate actively in the transition towards clean and renewable energy-driven transportation solutions.

As the world grapples with the challenges of climate change and energy sustainability, initiatives like this paper underscore the importance of interdisciplinary collaboration and creative problem-solving in addressing complex global issues. Through continued efforts to advance renewable energy technologies and promote sustainable transportation practices, we can build a more resilient and equitable future for generations to come

REFERENCES

[1] Y. Hu, M. Zhang, K. Wang, and D. Y. Wang, "Optimization of orderly charging strategy of electric vehicle based on improved alternating direction method of multipliers," *J. Energy Storage*, vol. 55, no. PB, p. 105483, 2022, doi: 10.1016/j.est.2022.105483.

[2] M. H. Cedillo, H. Sun, J. Jiang, and Y. Cao, "Dynamic pricing and control for EV charging stations with solar generation," *Appl. Energy*, vol. 326, no. July, p. 119920, 2022, doi: 10.1016/j.apenergy.2022.119920.

[3] M. Kubli, "EV drivers' willingness to accept smart charging: Measuring preferences of potential adopters" *Transp. Res. Part D Transp. Environ.*, vol. 109, no. July, p. 103396, 2022, doi: 10.1016/j.trd.2022.103396.

[4] P. Sharma and R. C. Naidu, "Optimization techniques for grid-connected PV with retired EV batteries in centralized charging station with challenges and future possibilities: A review" *Ain Shams Eng. J.*, no. xxxx, p. 101985, 2022, doi: 10.1016/j.asej.2022.101985.

[5] X. Liu and T. Feng, "Energy storage configuration for EV fast charging stations considering characteristics of charging load and wind-power fluctuation" *Glob. Energy Interconnect.*, vol. 4, no. 1, pp. 48–57, 2021, doi: 10.1016/j.gloei.2021.03.005.

[6] X. Yin, S. Lu, Y. Wang, and Z. Du, "Wireless charging structure and efficiency analysis based on wind–solar hybrid power supply system," *Energy Reports*, vol. 8, pp. 746–755, 2022, doi: 10.1016/j.egyr.2022.02.015.

[7] Q. Huang, Q. S. Jia, and X. Guan, "A Review of EV Load Scheduling with Wind Power Integration," *IFAC-Papers Online*, vol. 48, no. 28, pp. 223–228, 2015, doi: 10.1016/j.ifacol.2015.12.129.

[8] J. Engelhardt, J. M. Zepter, T. Gabderakhmanova, and M. Marinelli, "Energy management of a multi-battery system for renewable-based high power EV charging," *eTransportation*, vol. 14, no. August, p. 100198, 2022, doi: 10.1016/j.etran.2022.100198.

[9] J. Wu and Q. S. Jia, "On optimal charging scheduling for electric vehicles with wind power generation," *Fundam. Res.*, no. xxxx, 2022, doi: 10.1016/j.fmre.2022.04.023.