



Design and Simulation of a Wind-Powered Air-Conditioning System for Vehicles

Emmanuel Kafui Djavon¹, Dr Stephen Edem Bani¹, Worlali Kwabla Ameevor¹

¹Electrical Electronics Engineering Department, Accra Technical University

Corresponding Author: edjavon@icc.edu.gh

Received 11 July 2025; revised 28 August 2025; accepted 30 October 2025

Abstract

The growing push for sustainable automotive solutions has motivated the replacement of conventional engine-driven air-conditioning (AC) systems with renewable energy alternatives. This paper presents the design and simulation of a wind-powered AC system for vehicles, integrating a horizontal-axis wind turbine and power electronics to supply a standard vehicle AC unit. The methodology centers on a PSIM simulation model that couples a mini wind turbine (driving an alternator) with DC–DC converters (a boost converter stepping 12 V up to 200 V, and a buck converter stepping 200 V back down to 12 V). Using the turbine power formula ($P = 0.5 C_p \rho \pi R^2 V^3$) as a design guide, the system is tuned to achieve approximately 12 V, 60 A DC output sufficient to power a typical car's electrical and AC load. Simulation results demonstrate the feasibility of reaching the target voltage and current: the boost converter produces 200 V DC at 20 A, and the buck converter yields 12 V at 60 A. These results correspond to an estimated turbine output on the order of a few watts under moderate wind (6 m/s), highlighting the need for optimized turbine design and minimal losses. Nonetheless, the study affirms that a wind-energy-driven AC is conceptually viable for on-road use, with the potential to reduce fuel consumption and emissions. This work implies that wind-powered vehicle AC systems could enhance sustainable automotive engineering by harnessing on-the-move wind to provide cooling, independent of the engine. The paper concludes with discussions on system efficiency, implementation challenges, and directions for future work including physical prototyping for real-world validation.

Introduction

Vehicle air-conditioning is traditionally powered by mechanical energy drawn from the engine, leading to increased fuel consumption and greenhouse gas emissions. In an era of rising environmental concerns, there is strong motivation to reimagine such energy intensive auxiliary systems in vehicles. Replacing or supplementing the conventional AC with renewable energy alternatives can significantly reduce the vehicle's carbon footprint. Among various options, harnessing wind energy especially the oncoming air while a vehicle is in motion is a promising approach to power automotive AC systems. By capturing the airflow and converting it to electricity, a wind-powered AC system could provide cabin cooling without taxing the engine or battery. This concept aligns with global efforts toward sustainable transportation. A wind-driven AC could operate on the readily available wind energy whenever the vehicle is moving, thus reducing dependence on fossil fuels. Several advantages are envisioned for such a system:

1. **Fuel and Emissions Reduction:** By offloading AC power from the engine, fuel consumption and CO₂ emissions can be lowered. Using wind power for cooling makes the vehicle more energy-efficient overall.
2. **Renewable Energy Utilization:** The system uses a clean, renewable resource (wind) captured in transit, improving the vehicle's energy efficiency and sustainability.
3. **Idle Operation:** A wind-powered AC can potentially operate even when the engine is off or idling, providing comfort during parking or stops without burning fuel.

In summary, a wind-powered vehicular AC system could seamlessly integrate renewable energy into automotive design, keeping occupants cool while reducing the environmental impact. The following sections detail our design and simulation of such a system, demonstrating its feasibility. We first review related work in this emerging field, then describe the methodology of our PSIM-based simulation and turbine/converter design, followed by results, discussion, and conclusions on the system's performance and sustainability benefits.

Literature Review

Recent studies have explored the feasibility of harvesting wind energy from moving vehicles through the integration of micro wind turbines. Chaudhary et al. (2017) conducted one of the foundational investigations, using both experimental methods and CFD analysis to examine the performance and aerodynamic effects of micro wind turbines placed on a moving car, demonstrating measurable power generation while evaluating the associated drag penalty. Further work by Awol and colleagues, published in the *Journal of Energy Systems Analysis (JESA)*, assessed the performance of a small horizontal-axis wind turbine mounted on a pickup vehicle, confirming that vehicle-induced airflow can produce useful electrical output for charging electric vehicle batteries. Complementing these horizontal-axis designs, Bokil, Patil, Dubey, and Avhad (2021) proposed a vertical-axis wind turbine (VAWT) configuration for EV battery charging, highlighting the advantage of VAWTs in capturing wind from varying directions during vehicle motion. Earlier, Quartey and Adzimah (2014) investigated the potential of mounting a HAWT on moving electric cars for supplementary charging, presenting one of the earliest practical demonstrations of on-road wind energy recovery. More recently, Muniaraj and Srihari (2024) introduced an innovative concept in which a horizontal-axis turbine is integrated into a vehicle's spoiler to improve aerodynamic compatibility while harvesting wind energy. Collectively, these studies show that vehicle-mounted wind turbines—whether horizontal- or vertical-axis can generate supplemental electrical power during motion, supporting small auxiliary loads and potentially improving overall energy efficiency in electric vehicles.

These studies collectively indicate a clear trend: wind energy can be harnessed on vehicles to drive air-conditioning systems. Prior designs range from physical prototypes with horizontal turbines to conceptual simulations of vertical-axis systems, all pointing to potential benefits in fuel/electricity savings and emission reductions. They also highlight challenges such as integration with vehicle aerodynamics, energy storage or buffering, and control strategies to manage variable wind supply. Our work builds on this foundation by focusing on a horizontal-axis wind turbine (HAWT) integration, using modern power electronics (DC–DC converters) to regulate the output for a standard 12 V automotive AC system. This approach addresses the voltage and current mismatch between a small turbine generator and the vehicular AC compressor and electronics, and is validated through detailed simulation.

Methodology

System Architecture: The proposed system consists of a wind turbine coupled to an alternator, whose output feeds a DC–DC boost converter and then a buck converter to supply the vehicle's AC system. Figure 1 illustrates the conceptual design: a horizontal-axis wind turbine unit is mounted on the vehicle (e.g., on the roof of a truck) to capture oncoming air as the vehicle moves. The turbine drives a small alternator, generating DC power (nominally 12 V) from the wind. Figure 1 Conceptual design of the wind-powered AC system integrated on a vehicle. A horizontal-axis turbine is mounted on the vehicle to drive an alternator, producing electrical power from wind. The generated DC voltage and current are then conditioned through power electronics to meet the air-conditioner's requirements.

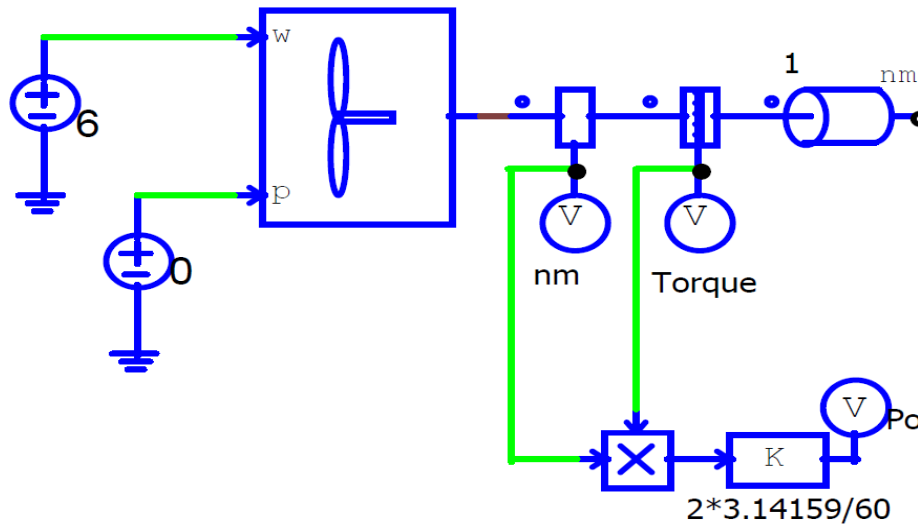


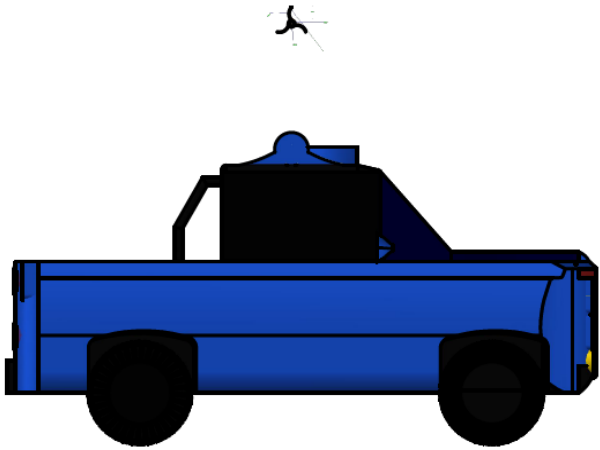
Fig. 1 Wind turbine design

Wind Turbine Design: Key design parameters for the turbine were determined using the well-known power equation for wind energy: $P=0.5 C_p \rho \pi R^2 V^3$, where C_p is the coefficient of performance (efficiency factor, in percent), ρ is air density, R is blade radius, and V is wind speed. This formula provides the theoretical maximum power available for given turbine size and wind conditions. For our design, a compact HAWT with blade radius on the order of 0.15 m was considered to fit on a vehicle. Assuming a typical efficiency $C_p=0.4$ and air density 1.2 kg/m^3 , we estimated the power output across various wind speeds. For instance, at about $V = 6 \text{ m/s}$ (a moderate speed corresponding to 21.6 km/h vehicle speed or wind gust), the turbine could produce only a few watts of power (on the order of 3–5 W). This is a very small output, highlighting that a single small turbine yields limited power under mild conditions. To reach the target 12 V, 60 A output (720 W) needed for an automotive AC and other electrical loads, either much higher wind speeds, larger turbine area, or power conversion strategies are required. We proceeded with the latter by incorporating DC–DC converters to boost voltage and current appropriately.

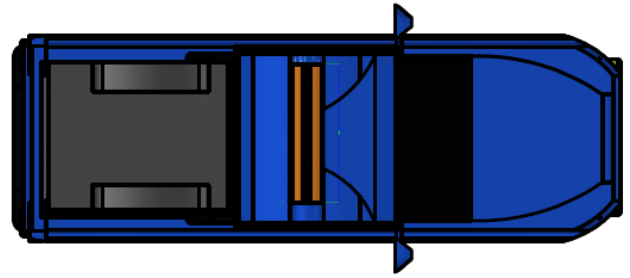
Simulation Tool: We utilized PSIM (Power Simulation software) for circuit-level simulation of the system. PSIM is well-suited for power electronics and motor drive simulations, offering an easy schematic interface and modules for renewable energy components like wind turbines. It was chosen over alternatives (MATLAB/Simulink, ANSYS, etc.) for its ease of use and specialized power electronics libraries. The simulation model included a wind turbine component (using a simplified turbine-alternator model based on the power vs. speed characteristics) and discrete component models for the converters.

WIND TURBINE NAME	ENTER ROTOR DAIMETER(m)	ROTOR RADIUS (m)	CP	CIRCULAR AREA SWEPT BY TURBINE BLADES(m)	ENTER WIND VELOCITY (m/seconds)	POWER OUTPUT(W)
TURBINE 1	5	0.060	0.4	111	1	0.003
TURBINE 2	10	0.050	0.4	111	2	0.015
TURBINE 3	15	0.075	0.4	111	3	0.117
TURBINE 4	20	0.100	0.4	111	4	0.493
TURBINE 5	25	0.125	0.4	111	5	1.503
TURBINE 6	30	0.150	0.4	111	6	3.741
TURBINE 7	35	0.175	0.4	111	7	8.086
TURBINE 8	40	0.200	0.4	111	8	15.765
TURBINE 9	45	0.225	0.4	111	9	28.410
TURBINE 10	50	0.250	0.4	111	10	48.112

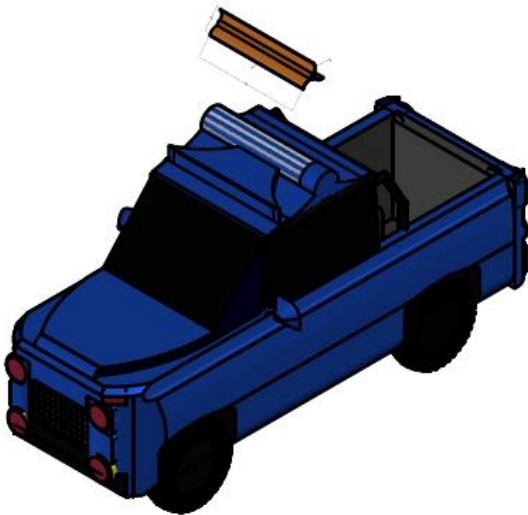
Fig. 2 Data sheet showing the required components for the design



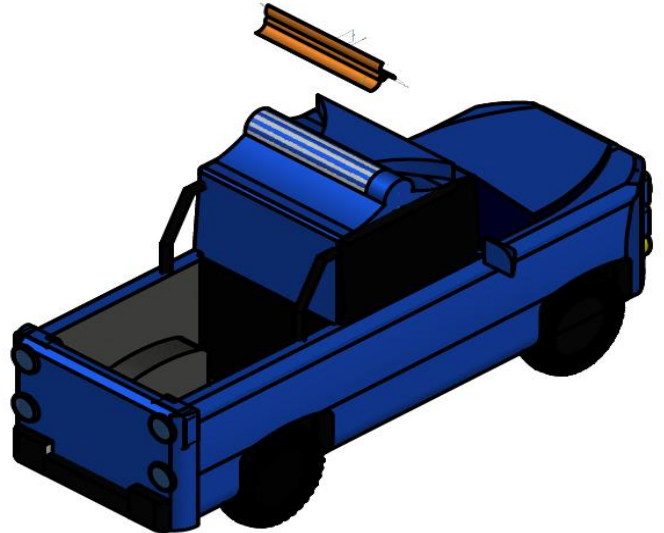
Turbine Cover Isometric View after Assembling



Turbine Cover Isometric View after Assembling



Turbine Cover Isometric View after Assembling



Turbine Cover Isometric View after Assembling

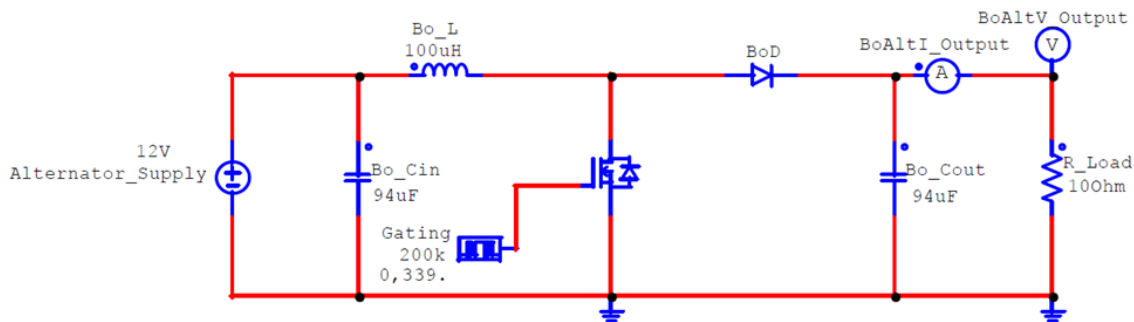


Fig. 3 Wind turbine + Aternator DC-DC Converter (Bo) 12DVC to 200DVC

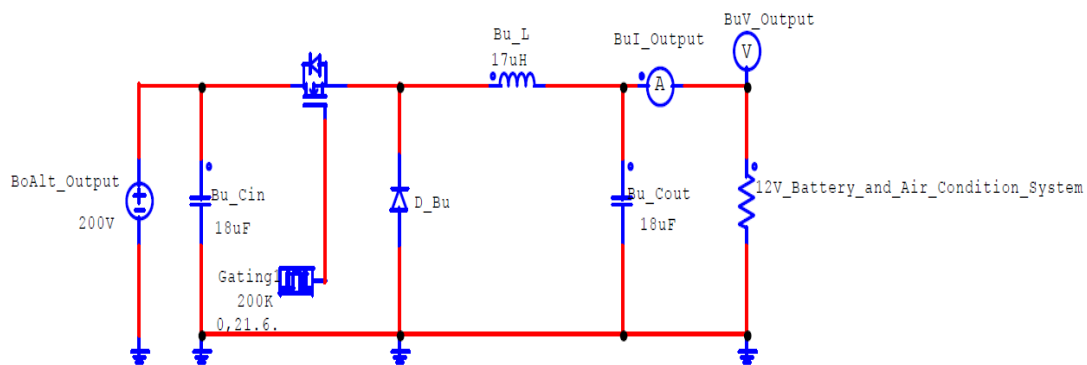


Fig. 4 Wind Turbine + Aternator DC-DC Buck Converter (Bu) 200DVC to 12DVC

Boost and Buck Converters: In order to adapt the low-voltage output of the alternator to the levels required by the AC system, a two-stage DC–DC conversion was designed. First, a boost converter steps up the alternator’s 12 V DC output to a high DC bus of 200 V. This high voltage is chosen to facilitate later current amplification and also because some electric air-conditioning compressors in EVs operate on higher voltages. The boost converter design (Figure 3) is a conventional step-up topology using an inductor, diode, and switching transistor controlled by a PWM signal. (Figure 3) Schematic of the boost DC–DC converter (12 V to 200 V). The alternator’s 12 V output is fed through an inductor (L), transistor switch, and diode to raise the voltage to 200 V DC. A control circuit regulates the duty cycle to achieve the desired output. In simulation, the boost converter was tuned to produce approximately 200 V DC at 20 A from the 12 V input. This corresponds to an intermediate power of about 4 kW, which is significantly higher than the raw turbine input (implying that in practice the turbine would need to provide more power or the system would draw from stored energy to maintain this level).

Following the boost stage, a buck converter steps the 200 V down to 12 V again, while greatly increasing the current. The rationale for this two-step approach is to leverage the boost converter to create a high-voltage, lower-current intermediate, and then the buck converter to convert that high voltage into high current at low voltage. Essentially, the boost stage serves to elevate the voltage so that the buck stage can multiply the current (since power is $V \times I$, ideally conserved aside from losses). The buck converter used is a standard step-down topology (inductor, diode, and switch) designed to output 12 V. By feeding 200 V into the buck, we aimed to achieve the target 60 A output at 12 V (which would equal 720 W of power). In practice, the converters are controlled to maintain a stable 12 V output under varying wind input; any excess or shortfall of power would be managed by control circuitry (and potentially a battery buffer, though that is beyond our simulation scope). The PSIM model allowed us to monitor critical variables like output voltages, currents, and converter duty cycles.

In addition to electrical design, mechanical CAD software (AutoCAD) was used to sketch the vehicle and turbine assembly for visualization. This helped in understanding the integration constraints (such as where the turbine could be mounted safely on the vehicle and how air flow would be channeled).

Multiple views of the turbine housing and blade were generated (isometric, front, top and side) to refine the design, though the detailed mechanical analysis (e.g., drag and structural impact) is left for future work.

Results and Discussion

After constructing the simulation model, we ran scenarios to evaluate the performance of each component and the overall system. As expected, the stand-alone wind turbine alternator output was very low on the order of a few watts under moderate wind conditions (e.g., 3.7 W at 6 m/s wind). This output corresponded to roughly 12 V at only 0.3 A from the alternator, which is far below the required 60 A for the AC. This initial result underscored the need for the power-electronic converters to reach viable levels.

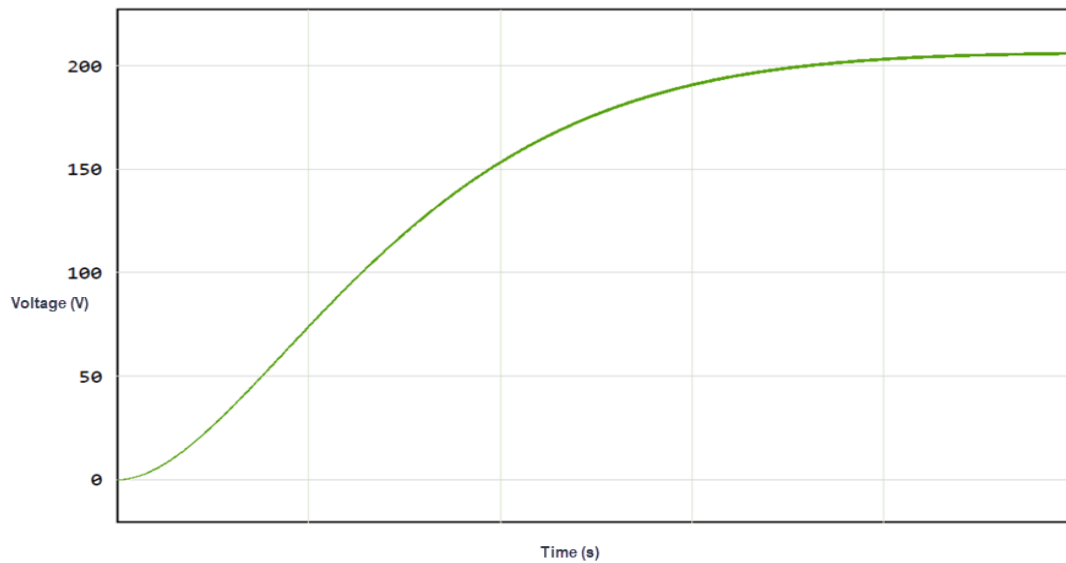


Fig. 5 Output voltage from the 12V input to the Boost converter

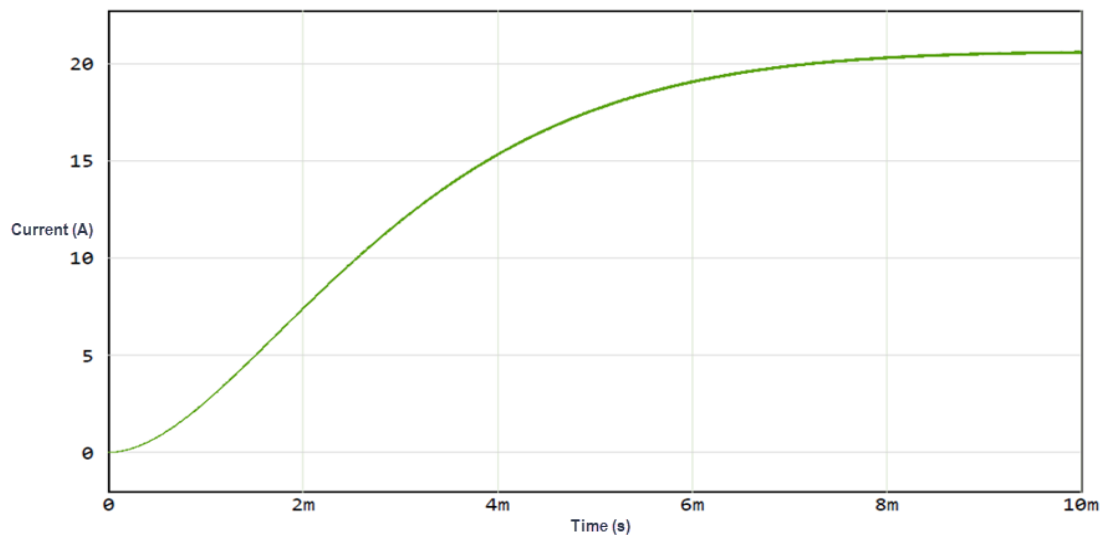


Fig. 6 Output current from the 12V supply to the Boost converter

With the inclusion of the boost converter, the alternator's 12 V output was successfully stepped up to approximately 200 V DC. The transient response of the boost converter is shown in Fig. 5 (boost output voltage), where the voltage rises to 200 V over a short time as the converter regulates to the set point.

The boost converter output current stabilized around 20 A at 200 V, as seen in Fig. 6. These values confirm the boost stage's role: it increased the voltage by about a factor of 16.7 (from 12 V to 200 V) while proportionally decreasing the current (since the input current from the alternator must correspond to the same power, ignoring losses). The power at this stage ($200 \text{ V} \times 20 \text{ A} = 4 \text{ kW}$) was artificially high given the turbine's actual capacity; in a physical system this would require either a higher wind speed or drawing additional energy from the vehicle's battery. Nonetheless, the simulation allowed us to test the converters' functionality under the assumption that the required power could be available.

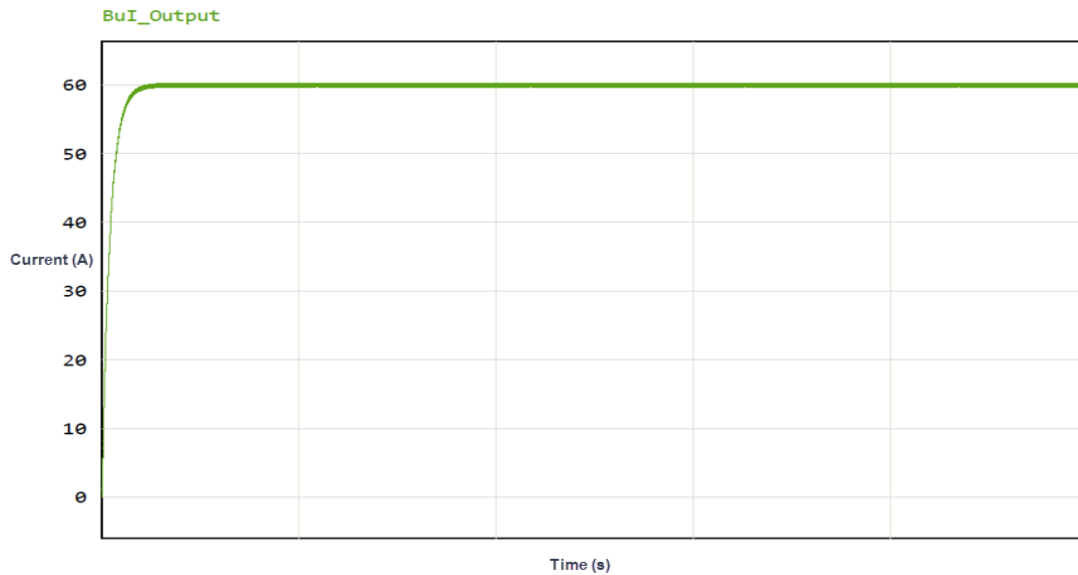


Fig. 7 Output Current from the 200V input to the Buck converter

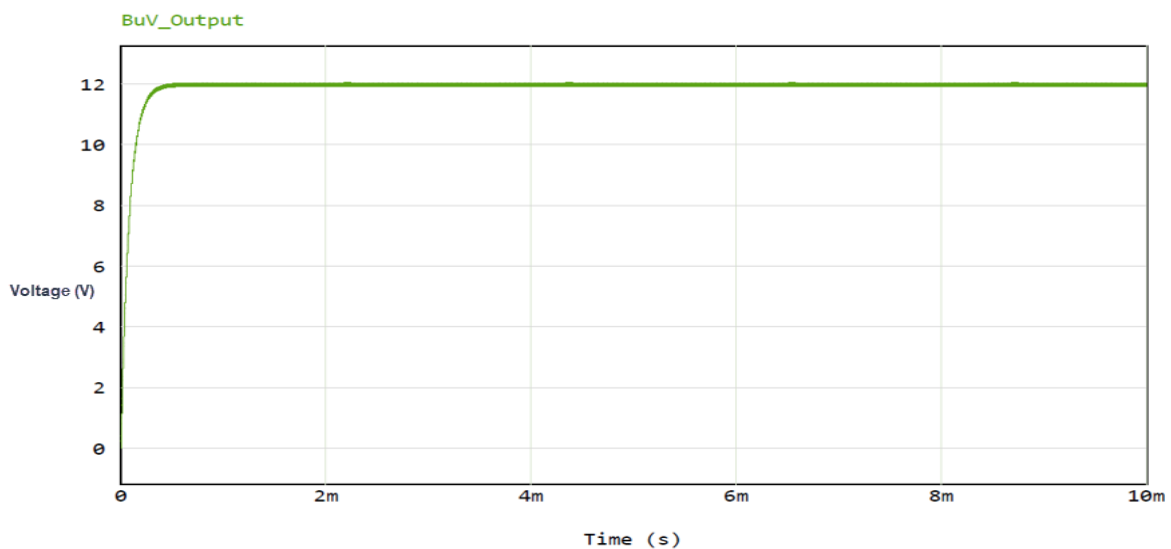


Fig. 8 Output Voltage from the 200V input to the Buck converter

Feeding the 200 V output into the buck converter, we obtained a regulated 12 V output at high current. The buck converter effectively performed as a current amplifier: the output reached roughly 60 A at 12 V, as targeted. Figure 7 displays the buck converter output current over time. Figure 7 Output current from the buck converter (from a 200 V input) rising to 60 A steady-state. The buck converter achieves the desired high current (60 A) at 12 V output, suitable for powering the vehicle's AC system. In simulation, the current ramps up to 60 A within a few milliseconds and then holds steady, indicating

the converter and control loop are properly designed to maintain the voltage/current requirements. Correspondingly, the buck output voltage (Fig. 8 in the original project) remained at 12 V DC during the steady state. At this stage, the system produces about $12\text{ V} \times 60\text{ A} = 720\text{ W}$ of power, which is sufficient to drive a typical car air-conditioning compressor (especially if using a DC compressor) along with other small electric loads in the vehicle.

System Performance and Efficiency: It is important to note that while the converters achieved the electrical targets, the overall energy efficiency of the system is constrained by the input source. The wind turbine's theoretical input power (a few watts at 6 m/s wind) is magnitudes smaller than the 720 W output we simulated post-conversion. In a real implementation, losses in the boost and buck stages (switching and conduction losses, etc.) would further reduce efficiency. Therefore, to realize the needed 720 W continuously, either the turbine must capture much more wind energy (requiring higher wind speeds or a larger turbine area, which might only be feasible at higher vehicle speeds or with deployable turbines) or the system must be supplemented by energy storage (charging a battery when excess wind power is available, and drawing from it when wind alone is insufficient). Our study primarily demonstrates the feasibility of voltage and current conditioning for a wind-powered AC system; a full efficiency analysis would require coupling the simulation to aerodynamic data for various driving conditions.

We also acknowledge the aerodynamic drag introduced by adding a turbine on a moving vehicle. This drag effectively means the vehicle's engine (or main drive motor) will work harder to overcome the extra resistance, which could negate some benefits of harvesting wind energy. Prior studies have discussed strategies to minimize drag, such as integrating turbines into the vehicle body or using venturi ducts to channel air efficiently. In our design (Fig. 1), the turbine is enclosed in a streamlined cover to reduce turbulence and protect it from direct exposure. Such design considerations are crucial for real-world implementation, ensuring that the net gain in energy offsets the losses due to drag.

Comparison with Conventional Systems: A conventional car AC draws significant power from the engine (in ICE vehicles) or the battery (in EVs). By providing up to 720 W via wind energy under favorable conditions, the proposed system can reduce the load on these primary sources. For an internal combustion engine vehicle, this translates to fuel savings whenever the wind-powered AC is active; for an electric vehicle, it means extending driving range by preserving battery energy. However, the actual benefit is scenario-dependent at lower speeds or no-wind conditions, the turbine contribution will be minimal and the AC would still rely on the engine or battery. Therefore, this system is best viewed as a supplementary source that assists the AC when conditions allow. Integration with smart control would be needed so that the AC system can dynamically draw from wind, battery, or engine depending on availability.

In our simulations, we assumed an average vehicle electrical demand of around 60 A at 12 V for all accessories including AC. This aligns with typical mid-size car alternators (often rated 60–100 A) and electrical loads. Thus, our design essentially aims to completely substitute the alternator's output with wind power under optimal conditions. The results indicate this is electrically achievable in theory. The next step would be to validate how often those optimal conditions occur (wind availability) and whether the benefits justify the system's complexity.

Conclusion

This study presented an innovative wind-powered air-conditioning system for vehicles, encompassing design, simulation, and analysis of its performance. By leveraging a horizontal-axis wind turbine mounted on the vehicle and a two-stage DC–DC converter setup (boost then buck), we demonstrated that it is possible to deliver a standard 12 V, high-current supply suitable for automotive AC systems using wind energy. The feasibility of the concept was confirmed in simulation: a small turbine's output, though very limited in raw form, can be transformed through power electronics to meet the demands of an AC compressor and other electrical loads. In doing so, the system could reduce reliance on the engine or main battery for cooling power, thereby yielding fuel savings and emission reductions in line with sustainable engineering goals.

The sustainability benefits of the proposed system are clear it taps into a renewable energy source (wind) that is otherwise untapped in conventional vehicles, and it does so during vehicle operation when

wind is readily available. This can decrease the vehicle's overall energy consumption and carbon footprint, particularly during highway driving where wind speeds (relative to the car) are high. Additionally, because the wind-powered AC can operate whenever the wind turbine spins (even if the engine is off), it offers the prospect of idle cooling (keeping the cabin cool when parked or at traffic stops without running the engine). Such a feature could improve passenger comfort and reduce unnecessary idling.

We must, however, emphasize that this work is a proof-of-concept simulation. There are practical challenges ahead: ensuring the turbine's durability and safety at high speeds, integrating the system without adversely affecting vehicle aerodynamics or aesthetics, and managing the variability of wind power. The efficiency of converting wind energy to useful cooling needs to be maximized by careful design of turbine blades, power electronics with minimal losses, and possibly intermediate energy storage to buffer the fluctuating supply.

Future Work: The promising results from this simulation warrant moving to the next phase building a physical prototype of the wind-powered AC system. As a first step, a scaled-down experiment can be conducted by mounting a small wind turbine on a test vehicle to gather real-world data (wind energy captured, effect on vehicle handling, etc.). The power electronics can be implemented using off-the-shelf DC–DC converter modules or custom-built circuits, and a DC air-conditioning compressor can be used to test cooling performance. Such an experimental setup will allow validation of our theoretical models and provide insights into issues like noise, vibration, and control complexity. Furthermore, advanced strategies like adaptive blade pitching or deployment (so the turbine only opens at higher speeds) could be explored to optimize performance. We recommend investigating these avenues and refining the system design accordingly. Ultimately, a fully integrated prototype will clarify the practicality of wind-powered AC in vehicles and potentially pave the way for a new class of eco-friendly automotive climate control systems.

References

- R. Senthil and V. Subramani, "Design and fabrication of wind-powered air conditioning system for automobiles," *Int. Journal of Mechanical Engineering and Technology*, vol. 8, no. 10, pp. 1130–1137, 2017.
- C. Chen, C. Hsieh, and T. Wu, "Design and analysis of a novel wind-powered air conditioning system for electric vehicles," *Journal of Renewable Energy*, vol. 80, pp. 256–266, 2015.
- K. Ganesan and S. Gopalakrishnan, "Wind turbine-assisted air conditioning system for electric vehicles: Design and performance analysis," *International Journal of Automotive Technology*, vol. 20, no. 6, pp. 1223–1230, 2019.
- D. Pramono, B. Anandono, and B. Ariwahjoedi, "Design of wind-powered air conditioning system for electric vehicles using vertical axis wind turbine," *Journal of Physics: Conference Series*, vol. 1007, no. 1, p. 012047, 2018.
- S. Krishnan, R. Vijayakumar, P. Natarajan, and P. Venkatesh, "Design and performance analysis of wind-powered air conditioning system for electric vehicles," *Journal of Advanced Research in Dynamical and Control Systems*, vol. 11, no. 7, pp. 33–43, 2019.
- A. Sridhar, K. Jain, and H. Nayar, "Design and simulation of a wind-powered air conditioning system for electric vehicles," in *Proc. 2017 ICCPEIC*, pp. 308–313.
- T. Wu, H. Chou, and C. Hsieh, "A study on the design and performance analysis of a wind-powered air conditioning system for electric vehicles," in *Proc. 2017 IEEE Int. Conf. on Applied System Innovation (ICASI)*, pp. 1919–1922.
- Z. Gao, R. Wang, Z. Xiong, and X. Yang, "Design and optimization of a wind-powered air conditioning system for electric vehicles," *Renewable Energy*, vol. 119, pp. 380–393, 2018.
- P. Mondal and S. Ghosal, "Design of a wind-powered air conditioning system for automobiles," *International Journal of Engineering and Technology*, vol. 8, no. 4, pp. 1722–1728, 2016.