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Wind Empowered Sustainable Highways

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Abstract: Wind energy offers many advantages, making it a compelling choice for sustainable power generation. Its renewable nature and environmental friendliness provide a clean energy solution that combats climate change and improves air quality. With cost-effectiveness, job creation, and economic benefits, wind energy strengthens local economies and promotes energy independence. Its scalability, land use efficiency, and technological advancements further enhance its appeal. By harnessing wind power, we can drive sustainable development, reduce greenhouse gas emissions, and pave the way for a cleaner, more resilient future. The wind flow generated by vehicle movements on high-speed highways could be captured using vertical turbines along the median to provide an anti-glare surface of high-speed roads while producing electricity to power up the streetlights and other major road infrastructure.
Keywords: Green Roads, Renewable Energy, Sustainable Development

I. INTRODUCTION

Wind Energy has been utilized to produce 4.5% of the electricity demands of India in the Fiscal Year 2022-23. The electricity produced from wind energy projects was 64.54 billion units from April 2022-January 2023. With most of the production limited to the Coastal regions, this mode of renewable energy is highly underestimated and limited to wind farms when it comes to use on a wider and more generic network, unlike Solar Energy which is now being used at almost every place it could be inventoried. The requirement of sustainable development and low Corban emission produce with this, it is utmost requirement to develop such a system which fulfil the current requirement and for the generations. Wind energy or wind power refers to the method of using the wind to produce electrical energy by rotating the turbines attached to the blade shaft. This energy can be used in the form of electricity using a generator. To illuminate the highways for better night visibility to reduce crashes, it is required to continuous illumination of highways. The wind force exerted by the high-speed vehicle is used to rotate the turbine, which is attached to the generator to produce electricity. The generated electricity can be stored and used for other purposes. Glare on Road Highways also pose a major problem in regards of Highway Safety.

II. LITERATURE REVIEW

Recent advancements in wind-empowered sustainable highways have focused on harnessing wind energy generated by vehicle-induced turbulence and optimizing the placement and design of wind turbines along roadways. Al-Aqel et al. (2020) demonstrated that small wind turbines can capture significant energy from the turbulent airflow created by passing vehicles, particularly at a 1-meter horizontal distance and 1-meter height with a 45-degree angle. This strategic positioning maximizes the energy harnessed from vehicle-induced turbulence by aligning the turbine blades with the most turbulent regions created by vehicles' passage. Sathyanarayanan et al. (2018) highlighted the use of Vertical Axis Wind Turbines (VAWTs) mounted on highway dividers with disc-type alternators. These VAWTs are advantageous in highway settings due to their ability to capture wind from any direction, making them suitable for environments where wind direction is variable and influenced by passing vehicles. The study found that wind speeds at the center of highways are higher than at pedestrian lanes because vehicles moving in opposite directions create a concentrated airflow in the middle, enhancing the turbines' efficiency. Akpinar et al. (2019) utilized Weibull and Rayleigh distribution models to conduct a detailed seasonal analysis of wind energy characteristics. These statistical models help in accurately estimating wind speed distributions and energy potential over different seasons. The study's findings include energy calculations and capacity factors for wind turbines, providing crucial insights into seasonal variations and optimizing turbine performance based on predictable wind patterns. Khan et al. (2021) introduced a novel reengineered design for VAWTs that focuses on utilizing the wind draft behind the turbine blades. This design innovation enhances the turbines' efficiency by capturing and converting more of the wind energy that would otherwise be lost. The reengineering effort involved optimizing the blade geometry and turbine placement to maximize the wind energy capture from both natural and vehicle-induced drafts. Pramod et al. (2022) demonstrated the integration of IoT platforms to monitor and control highway lights powered by wind-generated electricity.

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This system includes sensors and communication technologies that collect real-time data on wind speeds, turbine performance, and energy production. The IoT platform allows for remote monitoring and control, enabling adjustments to be made to optimize energy use and ensure reliable operation of the highway lighting system. This integration of smart technologies exemplifies the potential for IoT to enhance the efficiency and reliability of renewable energy systems in highway settings. These advancements collectively contribute to the feasibility and efficiency of sustainable highway systems by optimizing energy capture, integrating smart technologies, and improving the design and placement of wind turbines. They pave the way for greener transportation infrastructure, reducing reliance on conventional energy sources and promoting environmental sustainability.

III. VERTICAL AXIS WIND TURBINES – A WAY FORWARD

The proposed concept involves placing a vertical axis wind turbine (VAWT) on the highway divider, strategically positioned to harness wind from both sides of the road. This setup takes advantage of the increased wind speed created by passing vehicles, enhancing the turbine's efficiency and overall energy generation. By utilizing the available space in the highway center divider, this approach optimizes land use for sustainable electricity production.

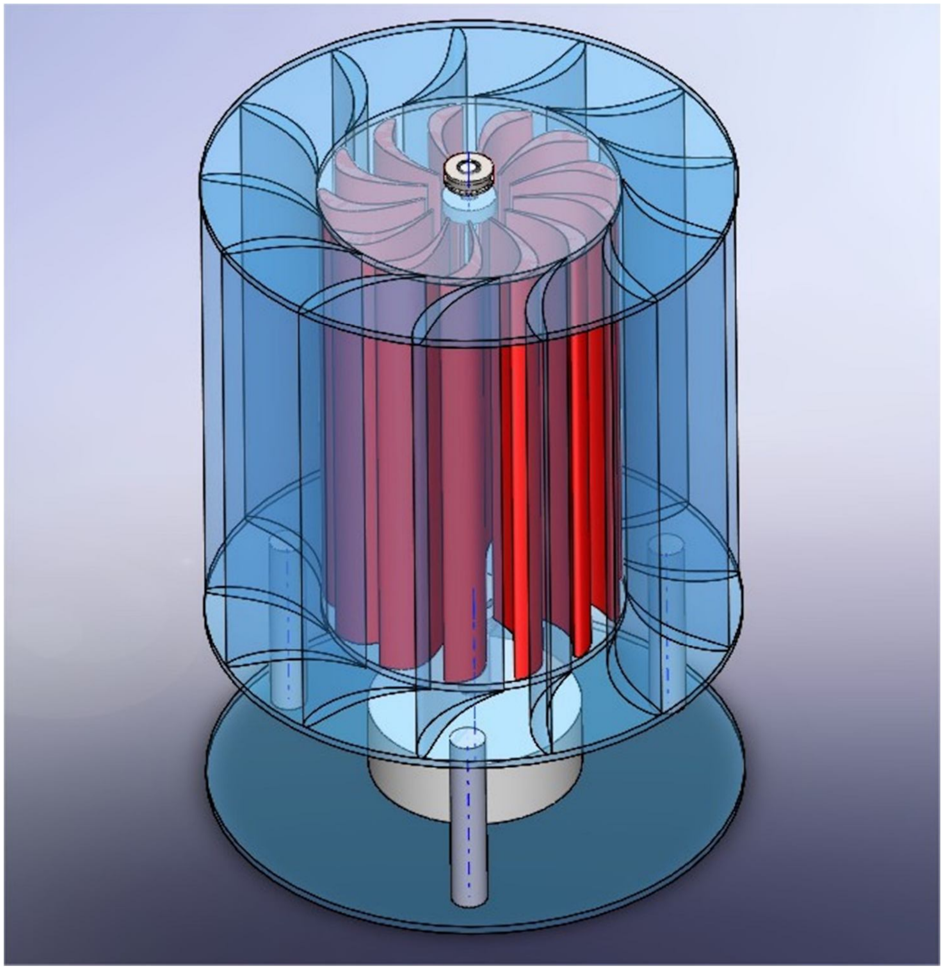

Figure 1: Vertical Axis Wind Turbines Prototype

Plastic Waste could be used to make Wind Blades and be installed at medians with or without crash barriers will be able to serve multiple functions, which will add to sustainable and safer transport. The Wind turbines shall be around 0.6m elevated from the road’s surface up to a height of 1.5m to gain maximum wind exposure from the road vehicles and provide spacing for highway crash barriers.

The maintenance needed for trees could also be saved while at the same time providing much safer and more efficient anti-glare tools in the terms of wind turbines present on the median of the roads. Also, in newly constructed roads, turbines could be raised on the medians so as to serve the function of crash barrier as well in case on median runover accidents.

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IV. PROPOSED DESIGN

On roads with crash barriers, it will serve as Crash barriers to reduce vehicle runoffs in opposite lanes while simultaneously converting the excessive wind energy produced by fast-moving vehicles on the road to electricity through a turbine motor mechanism. However, on Highways and expressways, it would also be effective in providing an anti-glare facility while driving due to its cutoff length of 1.5 m and still be efficient in producing electricity using wind energy.

Figure 2: Placement Concept of VAWT

Also, based on various literatures surveyed, the optimum spacing between each turbine could be 1 to 2 meters from centre to centre. Optimum wind velocity could be obtained between 1-1.5 meters for which the speed obtained ranges up to 4m/sec.
Factors taken into account for the design:

1) *Wind Speed:* A windmill's efficiency hinges on the wind's speed, as it propels the rotation of the turbine's axis and generator shaft, ultimately generating electric current.
2) *Blade Length:* The size of the blades is directly linked to the swept area, dictating the wind-catching capacity during each revolution. Larger blades with a greater swept area can generate more torque and capture more wind.
3) *Tower Height:* The height of the windmill tower significantly impacts its productivity, as higher altitudes are associated with higher wind speeds, leading to increased energy generation.
4) *Tower Design:* The construction of windmill towers is crucial, as they must not only support the windmill but also endure their own weight and wind resistance. Ensuring uniform and robust tower designs ensures a fair comparison.
5) *Blade Shape:* The choice of blade shape holds importance, as discovering an optimum design can boost the overall productivity of the windmill. Different blade shapes, such as flat, wing, tapered, or rounded edges, can influence performance.
6) *Surface Treatment:* Determining the best surface treatment for the blades is essential, as it protects them from environmental factors and enhances productivity.
7) *Tip Speed Ratio:* The tip speed ratio is a critical factor influencing windmill productivity, as it represents the rotational speed of the blades relative to the wind speed, directly impacting overall performance.

Based on the above parameters an ideal prototype for Vertical axis wind turbines have been adopted.

V. ANALYSIS

To estimate the energy production from VWATs, we started by determining the wind speed induced by vehicles. For this calculation, we assumed an average vehicle-induced wind speed of 10 m/s. This speed is representative of the wind generated by the movement of cars and trucks. The wind speed at the height of the VWAT, which is between 1.5 and 2 meters, is assumed to be the same as the vehicle-induced wind speed, i.e., 10 m/s. This assumption helps simplify the calculation by directly using the vehicle-induced wind speed to estimate the energy available to the turbine. The cross-sectional area of the turbine's rotor is calculated using a diameter of 1 meter. The formula for the cross-sectional area (A) of the turbine is:

Area, $A = \pi * (D/2)^2 = \pi * (1/2)^2 \approx 0.785\ m^2$

Using the formula for wind power: $P\_wind = (1/2) * \rho * A * V\_turbine^3$

where: - ρ (air density) = $1.225\ kg/m^3$
- A (cross-sectional area) = $0.785\ m^2$
- V_turbine (wind speed) = 10 m/s

$P\_wind = (1/2) * 1.225 * 0.785 * (10)^3 \approx 4{,}803$ W

To account for the efficiency of the turbine, which we assume to be 35%, the power output (P_output) is calculated as: $= \eta * P\_wind = 0.35 * 4{,}803 \approx 1{,}681$ W

Assuming the turbine operates for 8 hours a day (considering peak hours only), the daily energy production is:

E_daily = P_output * operating hours = 1,681 W * 8 h ≈ 13,448 Wh or 13.448 kWh

For annual energy production, assuming the turbine operates every day of the year:

E_annual = E_daily * 365 = 13.448 kWh * 365 ≈ 4,909.52 kWh

For the annual energy production from 100 VWATs: E_annual_100 = E_annual * 100
= 4,909.52 kWh * 100 ≈ 490,952 kWh

For 100 VWATs distributed along a 1 km stretch of road, the estimated energy production is substantial. Daily energy production is approximately 1,344.8 kWh per km, while the annual energy production reaches about 490,952 kWh per km

VI. APPLICATION

The energy produced by Vehicle Wind Activated Turbines (VWATs) can be effectively utilized in various ways to enhance sustainability and efficiency. One key application is powering road infrastructure, such as streetlights and traffic signals, which reduces operational costs and reliance on conventional energy sources. Additionally, VWAT-generated power can be integrated into local power grids to support renewable energy goals and decrease greenhouse gas emissions. It can also be used to charge electric vehicles (EVs), supporting the growing demand for electric transportation. In remote or off-grid areas, VWAT energy can provide essential power for lighting and communication systems. Furthermore, the energy can be stored in batteries to balance supply and demand, ensuring a reliable power source. By harnessing energy from vehicle-induced wind, VWATs not only contribute to practical energy solutions but also promote public awareness of renewable technologies and sustainable practices.

VII. CONCLUSION

Using wind energy on High-speed highways could be a beneficial step towards sustainable development, and along with its functional service of Crash Barrier and Anti-Glare element on the median, it would be a very effective step towards improving the safety of the road alongside. The study could further be utilized in Metro and Railways where the Wind Panels can be installed at the opening of tunnels where very high wind pressure is obtained. Wind walls could also be effectively used on the periphery of these tunnels, but their impact on the speed of the trains shall be further studied for implementation. Also, various inventive designs of wind panels, like wind wall panels, could be adopted at places that are not being utilized to their potential, like expired empty advertisement panels and the surface of tunnels of railways and roadways. The main emphasis is the efficiently available places of application of this technology, as wind energy is not a very new concept but is still not utilized up to its true potential.

VIII. ACKNOWLEDGEMENT

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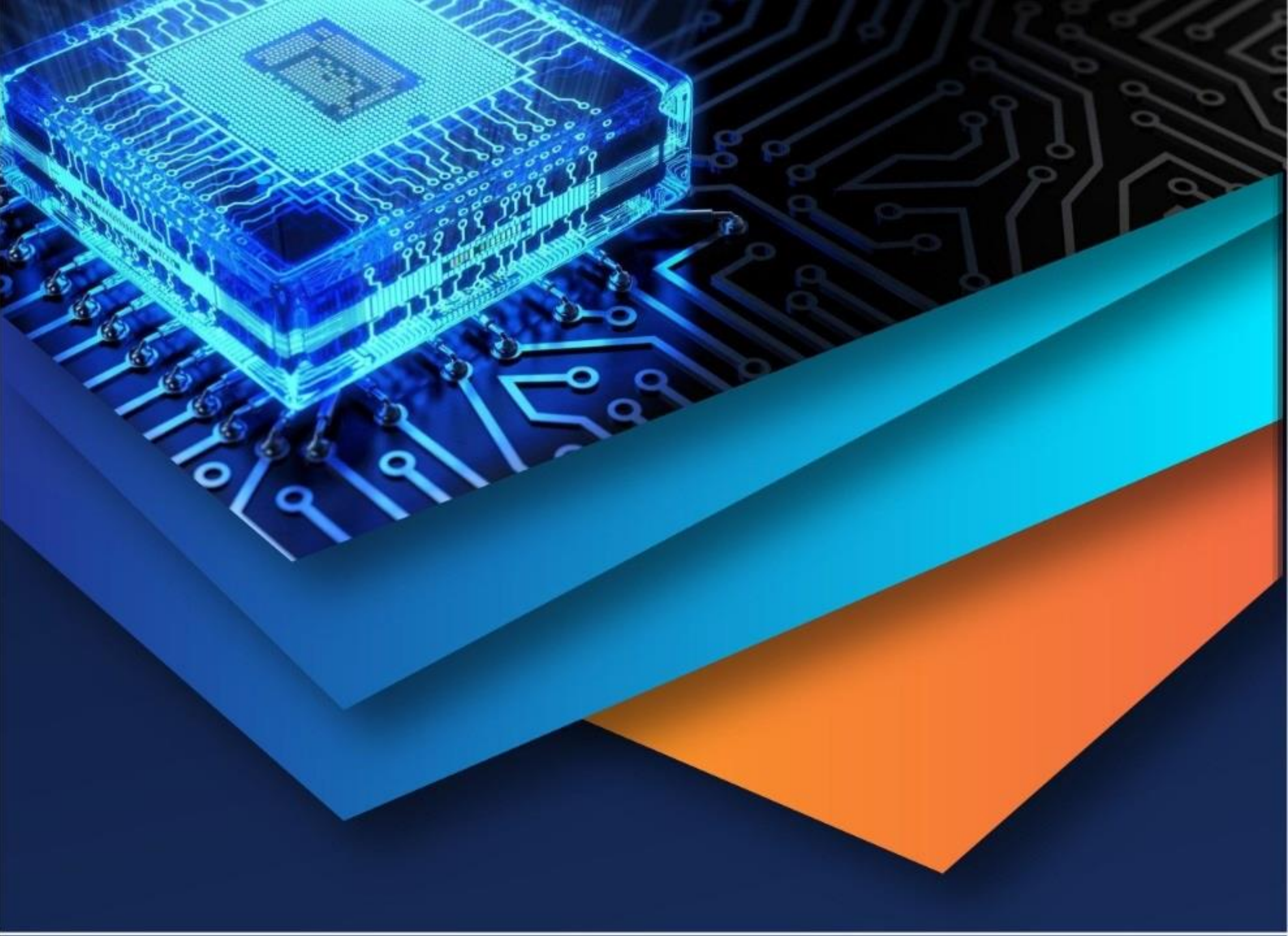

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