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Energy Harvesting Smart Cable-Stayed Bridge Using Traffic Vibration and Wind Flow

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Abstract: *The increasing demand for sustainable energy solutions has encouraged the integration of energy harvesting technologies into civil infrastructure. This study presents a smart cable-stayed bridge model capable of generating electricity using traffic-induced vibrations and wind flow. The system utilizes piezoelectric sensors to convert mechanical vibrations from moving vehicles into electrical energy, while small wind turbines harness aerodynamic forces. The generated energy can be stored and used for bridge lighting, monitoring systems, and smart infrastructure applications. The project demonstrates an innovative approach to utilizing existing transportation systems for renewable energy generation. Results indicate that such systems can contribute to sustainable development, reduce dependency on conventional energy sources, and enhance infrastructure efficiency.*

Keywords: Energy Harvesting, Smart Bridge, Piezoelectric Sensors, Wind Energy, Sustainable Infrastructure, Cable-Stayed Bridge.

I. INTRODUCTION

With rapid urbanization and increasing energy demand, sustainable and renewable energy sources have become essential. Conventional power generation methods contribute to environmental pollution and are not sustainable in the long term.

Bridges are critical infrastructure elements that experience continuous dynamic loads due to traffic and environmental forces such as wind. These forces often go unused. The concept of energy harvesting bridges aims to convert these mechanical energies into electrical energy using smart technologies.

This project focuses on a cable-stayed bridge model integrated with piezoelectric sensors and wind turbines to generate electricity. The system aims to utilize traffic vibration and wind flow efficiently, making bridges self-sustaining and intelligent infrastructure systems.

II. LITERATURE SURVEY

Piezoelectric Energy Harvesting: Previous studies show that piezoelectric materials can efficiently convert mechanical vibrations into electrical energy, especially in high-traffic areas..

Wind Energy Utilization: Small-scale wind turbines installed on bridges can capture wind energy generated by vehicle movement and natural airflow.

Smart Infrastructure Systems: Modern research emphasizes integrating sensors and energy systems into infrastructure for monitoring and sustainability.

Hybrid Energy Systems: Combining multiple energy sources (vibration + wind) improves overall efficiency and reliability of energy generation.

III. METHODOLOGY

The methodology includes design, energy conversion, and system integration.

3.1 Bridge Design Concept

The smart bridge model consists of:

- Cable-stayed structural system.
- Piezoelectric sensors embedded in deck.
- Wind turbines mounted on bridge sides.
- Energy storage and control system.

3.2 Energy Generation Principle

- Traffic load creates vibrations in the bridge deck
- Piezoelectric sensors convert vibrations into electrical energy
- Wind turbines rotate due to airflow and generate electricity
- Energy is stored in batteries for later use

3.3 Working Principle

- Vehicles pass over the bridge → vibrations generated
- Piezo sensors convert mechanical stress into electricity
- Wind turbines rotate due to wind/vehicle motion
- Generated power is collected and stored
- Energy is used for lighting and monitoring systems.

IV. MODELLING ANALYSIS

The model represents a small-scale cable-stayed bridge integrated with energy harvesting components.

Materials Used

- Piezoelectric sensors
- Mini wind turbines
- Bridge model materials (steel/wood/acrylic)
- Electrical wiring and storage battery
- LED lights for output demonstration

Model Features

- Simulates real traffic vibration
- Demonstrates wind energy generation
- Shows energy storage and utilization

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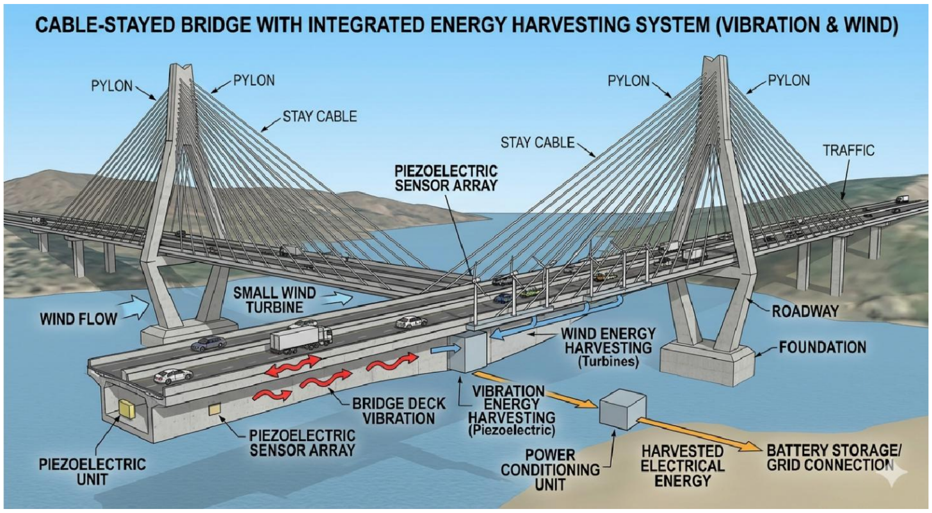

Figure 1: Energy Harvesting Smart Cable-Stayed Bridge Model

V. RESULT

The performance of the proposed energy harvesting smart cable-stayed bridge model was evaluated using a laboratory-scale experimental setup. The model was subjected to simulated traffic loads and controlled wind conditions to analyze the efficiency of energy generation.

Under dynamic loading conditions, the piezoelectric sensors installed in the bridge deck generated electrical output due to mechanical vibrations caused by moving loads. The voltage output varied with load intensity and frequency of vibration, showing higher energy generation under increased traffic simulation.

Simultaneously, the wind turbines mounted on the bridge structure produced electrical energy when exposed to airflow generated using fans. The energy output increased with wind speed, indicating the effectiveness of wind energy harvesting.

The combined hybrid system (piezoelectric + wind) resulted in improved overall energy generation compared to individual systems. The generated energy was successfully stored in a battery and used to power LED lighting, demonstrating practical application.

Key observations:

- Energy output increases with traffic density and load magnitude
- Wind energy acts as a supplementary source during low traffic conditions
- Hybrid system improves efficiency and reliability
- System is suitable for powering low-energy devices such as sensors and lighting
- The results confirm that integrating multiple energy harvesting methods enhances the feasibility of self-sustaining bridge infrastructure.

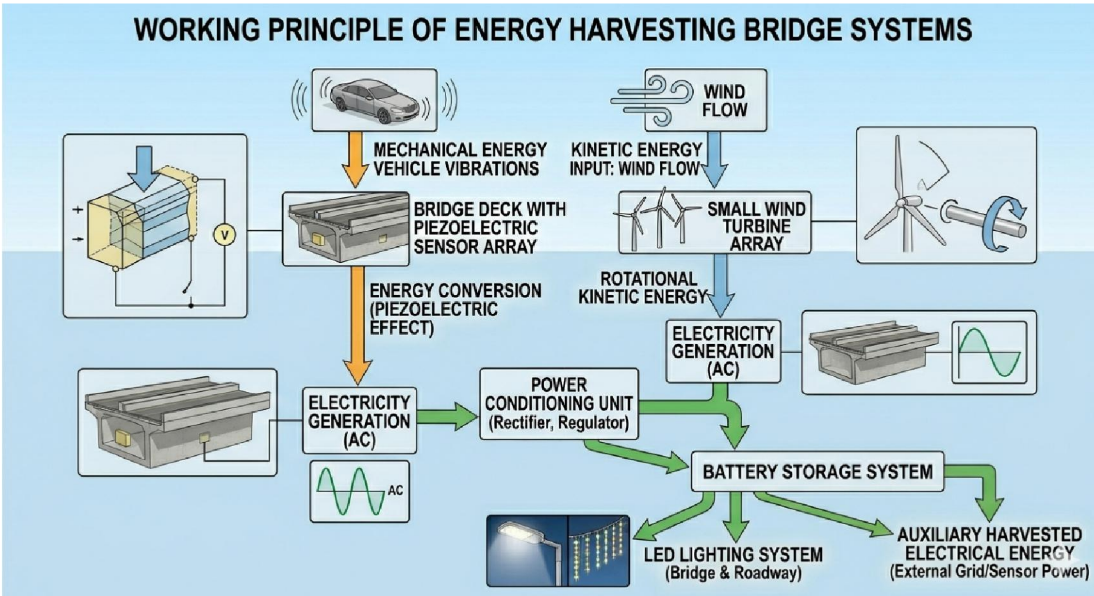

Figure 2: Working Principle of Hybrid Energy Harvesting System

VI. CONCLUSION

The study successfully demonstrates the concept of an energy harvesting smart cable-stayed bridge using traffic vibrations and wind flow as renewable energy sources. The integration of piezoelectric sensors and wind turbines enables efficient utilization of otherwise wasted mechanical and aerodynamic energy.

The experimental results indicate that the hybrid system provides better performance, reliability, and continuous energy generation compared to single-source systems. This makes the approach highly suitable for smart infrastructure applications such as street lighting, structural health monitoring systems, and traffic management devices.

Although the energy generated in the model is small, scaling up the system for real-world bridges can produce significant power, especially in high-traffic and high-wind regions. The system also reduces dependency on conventional energy sources and contributes to sustainable development.

However, challenges such as initial installation cost, durability of sensors, maintenance, and energy storage efficiency need to be addressed for large-scale implementation.

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