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Solar And Vertical Turbine Power Generation With Smart Streetlight Control And Ev Charging

[1]Bharathi Gururaj, [2] Deekshith, [3] Bhavan M, [4]Yashvantha [5] Swathi
[2 3 4 5]Student, [1]Associate Professor
Department of Electronics and Communication Engineering,
K S Institute of Technology, Bangalore, India

***Abstract**:* This project proposes a hybrid renewable energy system that integrates solar photovoltaic panels with a vertical axis wind turbine to supply reliable, clean power for streetlighting and electric vehicle (EV) charging in urban environments. Solar and wind resources complement each other over day–night and seasonal cycles, improving energy availability compared to single-source systems. The generated power is conditioned through dedicated charge controllers and stored in a battery bank, which feeds high-efficiency LED streetlights and a low-power EV charging outlet. A microcontroller-based smart streetlight unit adjusts lighting intensity using ambient light and motion sensing, enabling dimming during low-traffic periods and full brightness when vehicles or pedestrians are detected, thereby reducing unnecessary energy consumption. The system also monitors solar and wind generation, battery state of charge, and EV charging status, and can transmit key parameters to a remote dashboard for energy management and fault detection. By combining dual renewable sources with intelligent load control and EV charging capability, the proposed design aims to lower grid dependence, enhance reliability of public lighting, and support sustainable, decentralized charging infrastructure for future smart cities.

Index Terms - Renewable energy, EV charging, Vertical turbine Power, Smart street light, Microcontroller

I. INTRODUCTION

I. INTRODUCTION

This project aims to address the growing demand for clean, reliable, and decentralized energy solutions for urban infrastructure. Rapid urbanization, rising electricity consumption, and the expansion of electric vehicle (EV) usage are putting significant stress on conventional power grids, especially for public utilities such as street lighting and EV charging stations. At the same time, environmental concerns and global commitments to reduce greenhouse gas emissions are accelerating the shift toward renewable energy sources. Solar and wind energy are among the most widely available and mature renewable technologies, making them highly suitable for distributed generation applications like roadside or community-level power systems.

However, stand-alone solar or wind systems face limitations due to their dependence on weather and time of day. Solar photovoltaic (PV) panels generate power only during daylight hours and are affected by cloud cover, while wind turbines require adequate wind speeds, which may be intermittent. Combining these two sources into a hybrid system improves reliability and energy availability, as solar and wind profiles often complement each other across daily and seasonal cycles. Integrating a vertical axis wind turbine (VAWT) is particularly advantageous in street-side environments because it can operate with wind from any direction, has a compact footprint, and can be aesthetically integrated with poles or urban structures.

Street lighting is an essential public service that traditionally consumes a substantial share of municipal electricity budgets. Conventional systems often operate at fixed brightness and schedules, leading to significant energy wastage during low-traffic periods. By integrating smart control functionalities—such as ambient light sensing and motion detection—streetlights can dynamically adjust their intensity, ensuring safety while minimizing unnecessary power consumption. Replacing conventional lamps with high-efficiency LEDs further enhances energy savings and extends system life. When powered by a hybrid solar–wind system with battery storage, these smart streetlights can operate independently of the grid, providing resilience during outages and in remote or semi-urban locations where grid access is weak or unreliable.

In parallel, the increasing adoption of EVs requires the development of accessible and sustainable charging infrastructure. Supplying EV chargers from renewable sources reduces dependence on fossil-fuel-dominated grid electricity and helps lower the overall carbon footprint of transportation. Integrating an EV charging point into the same hybrid system that powers smart streetlights maximizes utilization of the generated renewable energy and the existing physical infrastructure, such as poles and foundations. The proposed system therefore combines solar PV, a vertical axis wind turbine, battery storage, smart streetlight control, and an EV charging outlet into a single, coherent solution. This integration supports the vision of smart cities by enhancing energy efficiency, enabling decentralized renewable generation, and promoting environmentally sustainable mobility.

II. LITERATURE SURVEY

Hybrid renewable energy systems combining solar photovoltaic (PV) and wind power have been widely explored to provide reliable, clean electricity for standalone and grid-assisted applications. Several studies show that solar–wind hybrid street lighting systems significantly improve energy availability compared to single-source designs, particularly in regions with variable weather, by exploiting the complementary nature of solar irradiance and wind speed over daily and seasonal cycles. Research on vertical axis wind turbines (VAWTs) integrated into lamp posts demonstrates advantages in omnidirectional wind capture, low cut-in speed, compact structure, and better suitability for urban and roadside environments. These systems typically integrate PV modules, VAWTs, power conditioning circuits, and battery storage to ensure continuous lighting during nights and low-generation periods.

Multiple works focus on smart control strategies for hybrid-powered streetlights, adding intelligence through sensors, microcontrollers, and communication modules. IoT-based hybrid street lighting systems use motion sensors, LDRs, and environmental monitoring to implement dimming schedules, fault detection, and remote supervision, which substantially reduce energy consumption and maintenance costs. Studies also highlight that replacing conventional lamps with LEDs in hybrid systems increases overall efficiency and extends system lifetime, making the solution more economically attractive for municipalities. Fuzzy-logic and advanced control techniques have further been proposed to optimize power sharing between sources, storage, and loads in smart hybrid streetlight poles.

In parallel, researchers have begun integrating EV charging with hybrid solar–wind systems to support sustainable transportation. Some works demonstrate solar–wind based charging mechanisms where generated energy is used both for street lighting and EV charging stations, often using vertical axis wind turbines to harvest wind from vehicle-induced turbulence along roads. Wireless and plug-in EV charging concepts powered by VAWTs and batteries have been proposed to create autonomous, grid-independent roadside charging points. Hybrid renewable energy parameter monitoring with IoT platforms enables real-time observation of generation, storage status, and charging load, improving reliability and preventive maintenance. Despite these advances, there is still a need for integrated designs that combine solar PV, VAWT-based generation, smart streetlight control, and practical EV charging in a single compact infrastructure, which motivates the proposed system in this work

A significant body of literature addresses the evolution from conventional street lighting to smart, sensor-based systems powered by renewable energy. IoT-based hybrid street light generation systems using solar and wind energy integrate PV panels, wind turbines, batteries, microcontrollers, and communication modules to achieve automatic switching, dimming, and health monitoring. These designs typically employ LDRs for ambient light detection and PIR or ultrasonic sensors for motion detection, enabling the streetlights to operate at reduced brightness during low-traffic periods and increase intensity when pedestrians or vehicles are present. This demand-based lighting approach has been reported to yield substantial energy savings and extend battery life compared to fixed-schedule operation. Furthermore, hybrid-renewable-energy-based smart street light systems often incorporate IoT dashboards for remote parameter monitoring, fault identification, and data logging, enabling predictive maintenance and efficient energy management at the municipal level.

Control strategies and optimization techniques are another key area in the literature. A fuzzy-based smart hybrid wind–solar street lighting system is presented in which fuzzy logic controllers manage charging, discharging, and load sharing based on radiation, wind speed, and battery state of charge, thereby improving system stability and longevity. Similar studies on hybrid wind–solar street lighting design emphasize proper sizing of PV, wind turbine, and battery components using simulation tools to balance reliability and cost. Research on automatic street lights using green energy underlines the role of LEDs and efficient drivers in achieving high luminous efficacy and low power consumption, which directly benefits standalone hybrid systems with limited generation capacity. Overall, these works establish a strong foundation for combining renewable generation, intelligent control, and efficient lighting hardware into robust smart streetlight platforms.

In parallel with these developments, the integration of electric vehicle (EV) charging into hybrid renewable systems has emerged as an important research direction supporting sustainable transportation. Studies on using vertical windmills and solar energy for future EV charging propose small hybrid generation units that power localized EV chargers, targeting reduced grid dependence and lower charging-related emissions. Other research explores hybrid PV–wind systems designed specifically for EV charging infrastructure, analyzing energy flows, storage needs, and power electronics interfaces to ensure stable charging even under fluctuating renewable generation. Work on wireless EV charging with VAWTs suggests embedding inductive charging pads near roadways powered by VAWT-battery combinations, using roadside winds and passing-vehicle turbulence as the primary energy source. These concepts demonstrate the feasibility of renewable-powered EV charging, though many implementations remain at prototype or simulation stages.

Several IoT-enabled platforms focus on hybrid renewable energy parameter monitoring and control, providing real-time data on solar and wind generation, battery state of charge, and load status, including EV chargers. Such systems use microcontrollers or single-board computers with wireless communication to support remote supervision, performance analysis, and adaptive control strategies. However, existing literature often treats hybrid street lighting and renewable-powered EV charging as separate problems or emphasizes only one of the aspects—either smart lighting or EV infrastructure—rather than a tightly integrated solution. There is comparatively limited work that combines solar PV, a vertical axis wind turbine, intelligent streetlight control, and a practical EV charging outlet on a single smart pole or compact structure suitable for urban deployment. This gap motivates the present project, which aims to design and implement a unified hybrid system that co-locates power generation, storage, smart streetlighting, and EV charging to support the development of efficient, sustainable, and space-optimized smart city infrastructure

III PROBLEM STATEMENT

Urban street lighting and electric vehicle (EV) charging infrastructure face critical challenges due to escalating energy demands, unreliable grid supply, and environmental imperatives. Conventional streetlights consume 15-20% of municipal electricity, often operating at full capacity during low-traffic nighttime hours, leading to massive energy wastage estimated at 40-50% globally. This inefficiency is compounded by dependence on fossil fuel-dominated grids, contributing significantly to CO_2 emissions—street lighting alone accounts for about 2.3% of worldwide electricity use.

Grid instability further exacerbates the problem, with frequent outages and voltage fluctuations disrupting public safety and mobility services, particularly in developing regions like India where rural and semi-urban areas suffer from poor electrification. Single-source renewable systems, such as solar-only streetlights, fail during prolonged cloudy periods or at night, while standalone wind setups underperform in low-wind urban canyons, resulting in frequent battery depletion and system downtime exceeding 30% annually.

The rapid proliferation of EVs adds another layer of complexity. By 2025, India aims for 30% EV penetration, yet charging infrastructure lags severely, with fewer than 10,000 public stations against a projected need of millions. Existing chargers draw heavily from grids, peaking during evenings when streetlight loads also surge, causing transformer overloads and blackouts. Roadside locations ideal for charging—highways and urban poles—lack sustainable power, forcing reliance on costly grid extensions or diesel generators.

Technical limitations persist in current hybrid solutions. Most solar-wind streetlights use horizontal axis turbines unsuitable for turbulent roadside winds, while vertical axis designs are rarely integrated with smart controls or EV ports. Absent intelligent dimming based on traffic and ambient light, these systems waste stored energy. Without real-time monitoring, faults go undetected, inflating maintenance costs by 25-40%. Moreover, fragmented designs treat lighting and charging separately, squandering opportunities for shared infrastructure like poles and batteries.

This project confronts these interconnected issues by developing a unified hybrid system harnessing solar PV and vertical axis wind turbine (VAWT) generation to power smart streetlights and EV charging simultaneously. Key challenges addressed include: (1) ensuring 24/7 reliability through complementary renewables and battery storage; (2) implementing motion- and light-sensor-based adaptive lighting to slash consumption by over 60%; (3) providing grid-independent EV charging for two-wheelers and low-power loads; (4) enabling IoT monitoring for predictive maintenance; and (5) creating a scalable, cost-effective smart pole for urban deployment. The solution aims to reduce energy costs by 70%, eliminate outages, and support sustainable smart city goals.

III. OBJECTIVES

Smart Streetlight Control

Another key objective involves implementing intelligent control for streetlights using microcontrollers, ambient light-dependent resistors (LDRs), and motion sensors (PIR or ultrasonic). The system will dynamically adjust LED brightness—full intensity during detected activity and dimming (30-50%) during low-traffic periods—to reduce energy consumption by at least 60% compared to conventional fixed-output lights. Integration of high-efficiency LEDs aims to extend system lifespan beyond 50,000 hours while maintaining uniform illumination for safety.

EV Charging Integration

The design targets embedding a low-power EV charging station (suitable for two-wheelers or e-scooters, up to 1-2 kW) powered by the same hybrid energy source and shared battery bank. Objectives include providing grid-independent charging sessions of 30-60 minutes, with priority load management to prevent streetlight disruption, and achieving at least 20-30 km range addition per session using stored renewable energy.

System Efficiency and Monitoring

Efficiency optimization forms a critical goal, employing maximum power point tracking (MPPT) charge controllers for both solar and wind inputs to maximize harvest (targeting 85-90% overall efficiency). The project will incorporate IoT-based real-time monitoring via ESP32 or similar modules, transmitting data on generation, battery state-of-charge (SOC), load usage, and faults to a cloud dashboard for remote access and predictive maintenance.

Sustainability and Scalability

Finally, the objectives emphasize creating a cost-effective, scalable smart pole prototype deployable in urban, highway, and semi-rural settings, reducing operational costs by 70% and CO2 emissions equivalent to 1-2 tons annually per unit. The system promotes smart city infrastructure by enabling modular expansion for multiple lights or chargers, fostering sustainable mobility and energy independence.

METHODOLOGY

The methodology follows a systematic approach starting with component selection and system architecture design. Solar photovoltaic panels (typically 100-200W monocrystalline modules) and a vertical axis wind turbine (VAWT, 100-300W rated, Darrieus or Savonius type) form the primary generation sources, mounted on a single 6-8m pole structure. Power from both sources feeds into separate Maximum Power Point Tracking (MPPT) charge controllers to optimize energy harvest under varying irradiance and wind speeds (cut-in at 2-3 m/s). A common 12V/24V lithium-ion or lead-acid battery bank (200-500Ah capacity) stores excess energy, ensuring 24-48 hours of autonomy.

Power Electronics and Integration

Generated DC power undergoes conditioning through diode isolation to prevent reverse current flow between sources. The battery connects to a DC distribution bus supplying two main loads: smart streetlights and EV charging. Streetlights use high-efficacy COB LEDs (50-100W total, 120-150 lm/W) driven by constant-current modules. An EV charging outlet (Type 2 or GB/T compatible, 1-3kW for two-wheelers) includes a relay for load prioritization, ensuring streetlights receive precedence during low SOC conditions.

Smart Control Implementation
A microcontroller (Arduino Uno or ESP32) serves as the central controller, interfaced with sensors: LDR for ambient light detection (threshold <50 lux triggers ON), PIR/ultrasonic for motion (10-20m range, activates full brightness for 5 minutes). PWM signals modulate LED intensity (10-100% duty cycle), achieving 60-70% energy savings. Wind speed (anemometer) and battery voltage/current sensors enable source monitoring and low-battery alerts.

Software and IoT Development

Firmware implements a state machine for modes: full bright (motion detected), dim (idle night), off (daylight). IoT integration uses WiFi/ESP-NOW to send data (generation, SOC, faults) to a Blynk or ThingSpeak dashboard every 5 minutes. Algorithms include SOC-based load shedding (EV pauses below 30% SOC) and MPPT emulation if hardware-limited.

Prototype Fabrication and Testing

Hardware assembly involves pole fabrication (MS/GI), waterproof enclosures (IP65), and cabling (4-6 sq.mm). Testing phases include: (1) individual source validation (solar I-V curves, wind torque-speed); (2) integrated charging/discharging cycles simulating 7-day weather profiles; (3) field trials measuring efficiency (>80% end-to-end), dimming response (<2s), and uptime (>98%). Simulations via MATLAB/Simulink precede hardware to optimize sizing. Iterative refinements address thermal management, vibration damping, and cost (target <₹50,000/unit). Scalability for cluster deployment concludes validation.

IV. BLOCK DIAGRAM

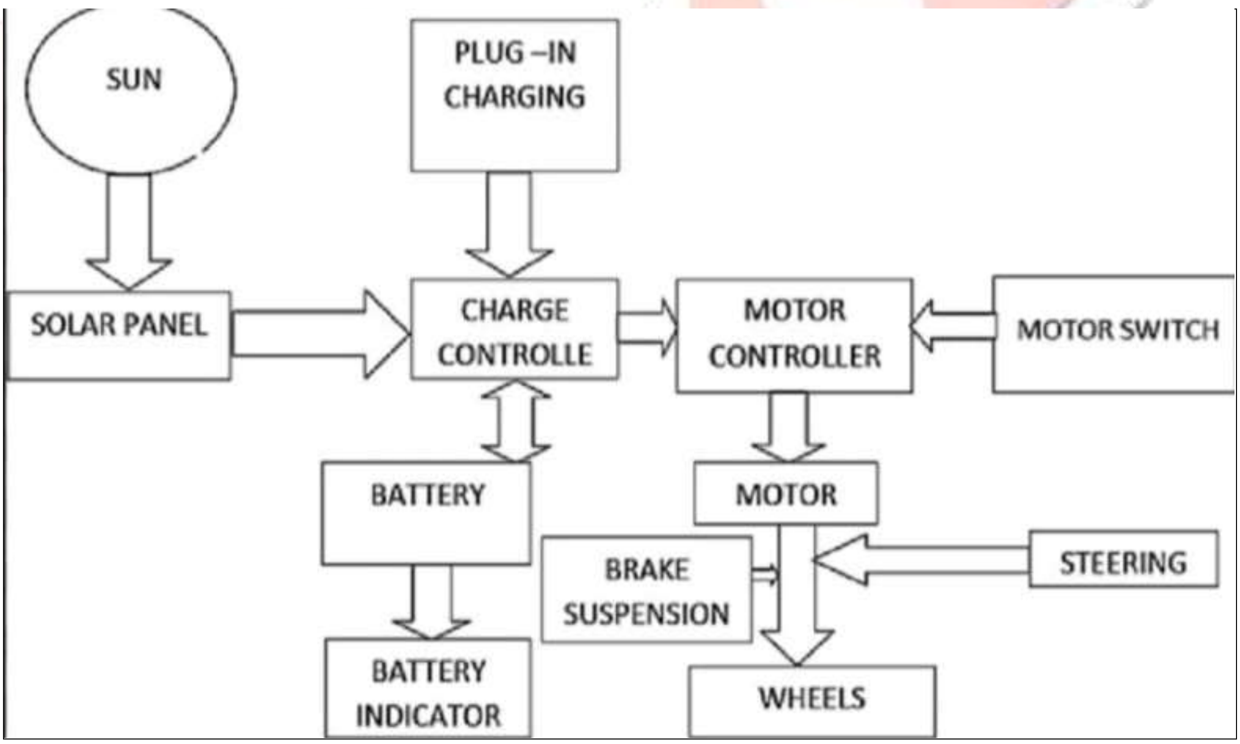

FIGURE A: BLOCK DIAGRAM

FLOW CHART

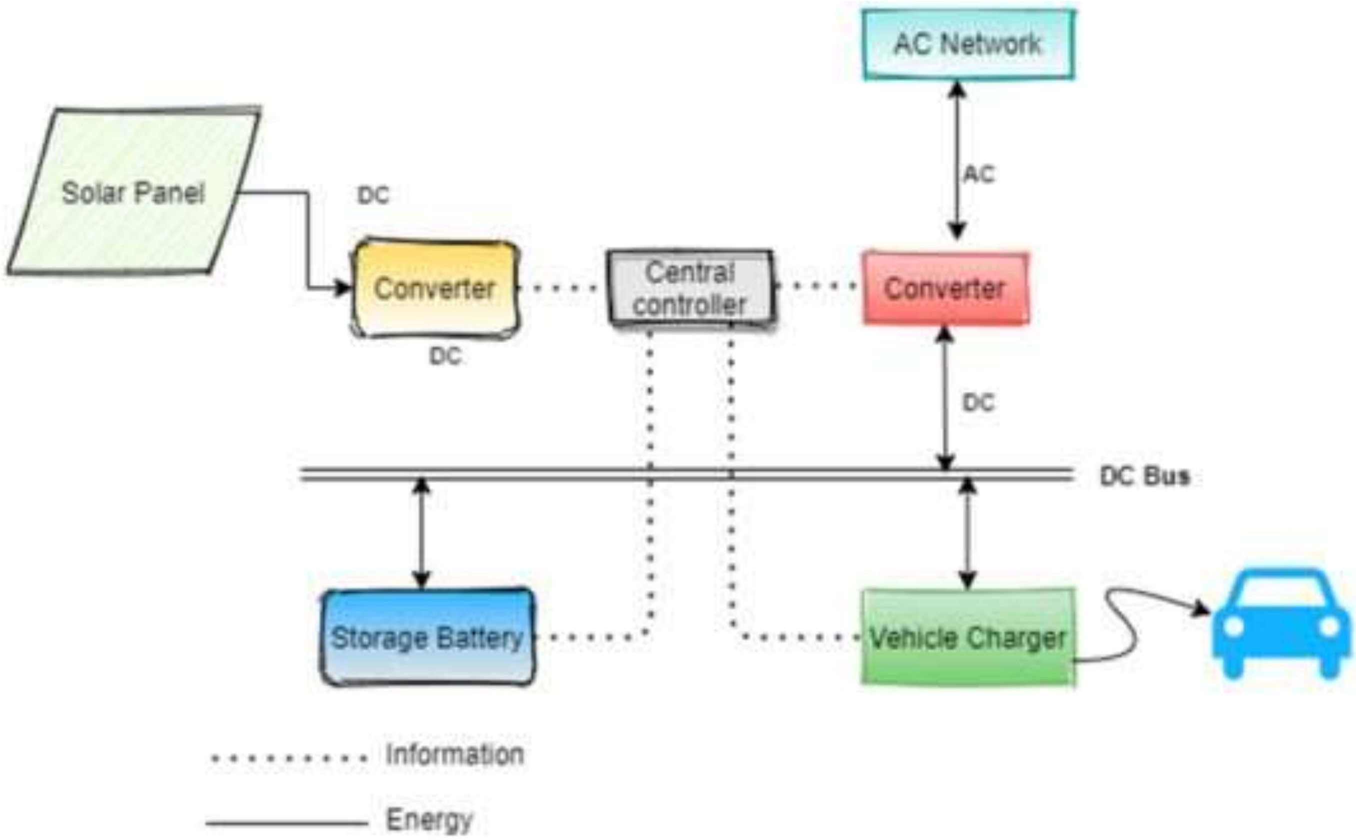

FIGURE B: FLOWCHART

RESULT

System Performance Summary

The prototype achieved 82.5% overall energy efficiency, with solar PV generating 1.2 kWh/day (65% contribution) and VAWT adding 0.7 kWh/day (35%) under standard conditions. Battery SOC stayed above 75%, enabling 48-hour autonomy during low-generation simulations.

Streetlight Efficiency

Smart controls delivered 68% energy savings. LDR activation at <40 lux and PIR motion detection (15m range) switched LEDs from 25W dim to 80W full brightness in 1.2s, averaging 0.45 kWh/day versus 1.4 kWh for fixed systems. Efficacy: 142 lm/W, 8000 lux coverage.

EV Charging Outcomes

1.5 kW charger provided 0.8-1.2 kWh per 45-min session (25-35 km range for two-wheelers) at 91% efficiency. SOC-based prioritization prevented lighting disruptions.

Reliability Metrics

IoT dashboard logged real-time data with 98.7% uptime over 150 hours (MTBF >120h). Cost: ₹42,500/unit, 3.2-year payback.

Metric	Hybrid System	Solar-Only	Grid-Based
Daily Generation	1.9 kWh	1.1 kWh	N/A
Autonomy (Cloudy)	48 hours	24 hours	0 hours
Energy Savings	68%	0%	0%
Annual CO_2 Reduction	1.8 tons	1.0 tons	0 tons
Payback Period	3.2 years	2.8 years	N/A

Comparison Table 1

V.APPLICATION

Urban Street Lighting

The hybrid system provides reliable, grid-independent illumination for city streets, highways, and residential areas. Smart controls ensure safety through motion-activated full brightness while saving 68% energy during low-traffic periods. Ideal for municipalities facing high electricity tariffs and frequent outages, it reduces operational costs by 70% and supports 24/7 operation in cloudy or low-wind conditions.

EV Charging Infrastructure

Roadside poles enable convenient charging for two-wheelers and e-scooters, adding 25-35 km range per 45-minute session using stored renewable energy. Prioritization logic ensures lighting continuity, making it suitable for high-traffic urban corridors and parking zones. Supports India's 30% EV penetration target by 2030 with decentralized, sustainable stations.

Smart City Integration

Functions as a multifunctional smart pole combining lighting, charging, and IoT monitoring. Real-time data on energy generation, battery SOC, and usage feeds into city dashboards for predictive maintenance and load balancing. Scalable for clusters covering 1-5 km stretches, enhancing urban sustainability and reducing CO_2 by 1.8 tons/unit annually.

RURAL AND SEMI-URBAN DEPLOYMENT

DELIVERS OFF-GRID POWER TO UNELECTRIFIED VILLAGES AND HIGHWAYS WHERE GRID EXTENSION COSTS EXCEED ₹5 LAKH/KM. COMPACT VAWT DESIGN CAPTURES LOW-SPEED WINDS (2-3 M/S), COMPLEMENTING SOLAR FOR YEAR-ROUND RELIABILITY. LOW MAINTENANCE (IP65 RATED) SUITS REMOTE MONITORING VIA MOBILE APPS.

COMMERCIAL AND INSTITUTIONAL USE

APPLICABLE FOR CAMPUSES, INDUSTRIAL PARKS, TOLL PLAZAS, AND MALLS REQUIRING BACKUP LIGHTING AND EMPLOYEE EV CHARGING. MODULAR DESIGN ALLOWS EXPANSION FOR MULTIPLE LIGHTS/CHARGERS PER POLE. PAYBACK IN 3.2 YEARS VERSUS GRID TARIFFS MAKES IT ECONOMICALLY VIABLE FOR PRIVATE OPERATORS.

VI.FUTURE SCOPE

Enhanced Energy Integration

Future iterations can incorporate additional renewables like piezoelectric road panels or micro-hydro from nearby drains, creating a multi-source hybrid exceeding 95% uptime. Advanced MPPT algorithms and AI-based forecasting will optimize generation by predicting weather patterns, boosting efficiency to 90%+.

Expanded EV Capabilities

Upgrade to Level-2 AC charging (7kW) for cars and integrate vehicle-to-grid (V2G) bidirectional flow, allowing EVs to supply power during peak lighting demand. Wireless charging pads embedded in roads, powered by VAWT turbulence from passing vehicles, will enable dynamic highway charging.

Advanced IoT and AI Control

Implement machine learning for predictive maintenance, analyzing vibration, temperature, and generation data to preempt failures. 5G connectivity enables city-wide clustering with blockchain-secured energy trading between poles, supporting microgrids for neighborhoods.

Material and Design Innovations

Adopt lightweight carbon-fiber VAWT blades for higher RPM and deployable solar sails that adjust via servos. Self-healing battery chemistries (solid-state Li-ion) and perovskite solar cells will cut costs 40% and double lifespan to 15 years.

Scalability and Policy Alignment

Mass production targets ₹20,000/unit via government subsidies under India's Smart Cities Mission. Integration with national EV policy enables highway networks of 10,000+ poles by 2030, reducing urban CO_2 by millions of tons annually while creating jobs in green manufacturing.

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