

Green Highways: Harnessing Renewable Energy for Sustainable Power Generation with IoT Monitoring

Dr. Narendra Kumar Yegireddy^{1*}, Dr. M N V S S Kumar², Dr. Gottapu Santosh Kumar³

Abstract:

In today's modern world, electricity plays a paramount role in our day-to-day existence. However, the stark reality is that our non-renewable energy sources are depleting at an alarming rate. Consequently, there is an urgent need to shift our focus from conventional energy sources to non-conventional, sustainable alternatives for electricity generation. The Dual Power Generation system represents an innovative solution that integrates both solar and wind energy plants, offering a reliable and uninterrupted power supply.

This system capitalizes on the power of the wind, harnessing the pressure created by moving vehicles to rotate windmill blades and generate electricity. The wind turbulence experienced on highways is directly influenced by factors such as the size and speed of automobiles and the frequency of traffic. Simultaneously, the system taps into another abundant and free energy source, solar power generation. Solar panels are strategically positioned on dividers, enabling them to capture energy from sunlight during the day and even from vehicle headlights during the night.

To ensure efficient operation and monitoring of both energy sources, a sensor network is employed, and the generated data is seamlessly uploaded to the cloud through the Internet of Things (IoT) technology. This dual approach not only addresses the growing energy demand but also promotes sustainability by reducing our reliance on depleting non-renewable resources. It represents a visionary step towards a greener and more sustainable energy future.

Keywords: Dual Power Generation, Renewable Energy Integration, IoT Monitoring, Sustainable Electricity

1. Introduction

In our contemporary daily lives, the insatiable demand for electrical energy significantly outpaces the available supply. Presently, the primary sources of electrical energy that power our world predominantly rely on conventional resources such as coal, diesel, and nuclear power. However, these conventional sources come laden with substantial and wide-ranging drawbacks, further underscoring the pressing need to transition towards alternative and sustainable energy solutions. One of the most critical disadvantages of conventional energy resources is the significant environmental impact they carry. For instance, coal power plants release copious amounts of pollutants, including ash, into the atmosphere. Not only does this contribute to air pollution, but it also creates a long-term challenge of ash disposal and environmental contamination [1]. In the case of nuclear energy, the generation of power is accompanied by the production of hazardous nuclear waste. The proper handling, storage, and disposal of this radioactive waste present substantial financial burdens and, more critically, pose a considerable risk to human health and the environment. The hazards associated with nuclear waste are especially concerning, as they persist for thousands of years, necessitating robust safeguards and management strategies.

Adding to these concerns is the depletion of conventional energy resources. Fossil fuels such as coal and diesel are finite, and their availability is dwindling at an alarming rate. As we grapple with the inevitability of their eventual depletion, we find ourselves at a critical juncture in human history [2]. The urgency to identify and embrace alternative, reliable, and sustainable energy sources has never been more pronounced. In this context, the emphasis shifts towards non-conventional energy resources, which hold the promise of revolutionizing our energy landscape. Non-conventional energy resources encompass a wide spectrum of options, including solar, wind, hydroelectric, geothermal, and biomass, among others.

Corresponding Author: Dr. Narendra Kumar Yegireddy

1.Professor, EEE department, Satya Institute of Technology and Management, Vizianagaram, Andhra Pradesh, India – 535003

Email: narenyegireddy@gmail.com

2Associate Professor, Department of Electronics and Communication Engineering, Aditya Institute of Technology and Management, Tekkali, Srikakulam, Andhra Pradesh, India

3Department of Civil Engineering, Gayatri Vidya Parishad College of Engineering, Visakhapatnam, Andhra Pradesh 530048

These sources of energy are inherently more eco-friendly, sustainable, and often cost-effective when compared to their conventional counterparts. Their utilization results in significantly reduced greenhouse gas emissions, thereby contributing to mitigating climate change and environmental degradation [3].

Moreover, non-conventional energy resources tend to be renewable, ensuring a continuous and dependable energy supply. Solar energy harnesses the abundant sunlight that bathes our planet, wind energy capitalizes on the power of the wind, hydroelectric energy taps into the flow of water, geothermal energy derives from the Earth's internal heat, and biomass energy utilizes organic materials and waste to generate power. The diversity of these resources allows for adaptable and region-specific energy solutions that cater to varying geographical and climatic conditions. As we confront the complex challenges posed by the increasing global demand for electricity and the environmental ramifications of conventional energy production, the transition to non-conventional energy resources becomes not only an imperative but also a visionary and responsible choice [4]. It represents our commitment to a sustainable, clean, and secure energy future and holds the key to reducing our carbon footprint and safeguarding the well-being of present and future generations. The era of non-conventional energy has arrived, and its potential to reshape our energy landscape and drive progress towards a more sustainable and environmentally conscious world is limitless.

On highways, vehicles travel at high speeds, creating wind turbulence as they move. The passage of a vehicle disturbs the air above the highway, resulting in low wind pressure and a significant vortex trailing behind the vehicle. This disturbed air seeks to fill the void created by the moving vehicle, leading to substantial wind turbulence along the highway. This wind turbulence directionally follows the vehicle towards the center of the low-pressure field. The intensity of wind turbulence on highways is directly influenced by factors like vehicle size, speed, and traffic frequency. To harness wind energy effectively in this context, wind turbines must be capable of utilizing moderate wind speeds. A combination of two Vertical Axis Wind Turbines (VAWT) - the Savonius and H-type Darrieus Turbine - can efficiently capture this highway-side wind energy [5].

Additionally, our approach incorporates the utilization of another abundant and free energy source: solar power. Solar panels are strategically placed on highway dividers, allowing them to generate electricity from sunlight during the day and even harvest energy from vehicle headlights during the night. Although nighttime energy generation is not guaranteed, it can still provide a significant contribution, especially in the range of 30-40% efficiency. To enhance solar energy efficiency, we implement a solar tracking system. The energy produced by both wind and solar sources is continuously monitored through a sensor network, and the data is uploaded to the cloud using IoT technology. This data serves as a valuable resource for future analysis and planning. The data is stored on the Thingspeak cloud platform [6]. Moreover, an automatic street light controller is integrated into the system to ensure efficient utilization of the generated power. The streetlights are activated only when there is movement on the road, thus conserving energy and reducing wastage. The stored energy can be effectively used for various applications, including street lighting and toll gates.

2. Literature Review

A single wind turbine harbours the remarkable potential to serve as a primary electricity source for households, ensuring the safety and comfort of urban environments. This versatile turbine boasts adaptability in terms of installation locations, ranging from parks, seashores, and rooftops to residential areas. Among these choices, highways emerge as the most favourable placement for this innovative device. High-capacity vehicles, particularly buses, hold the key to substantial wind energy generation, especially when coupled with specialized vertical turbines equipped with elongated blades. This design approach is twofold in its benefits – it not only minimizes the ground space required but also simplifies assembly and disassembly procedures, ultimately enhancing the turbine's durability and operational efficiency. Additionally, the integration of solar panels at the turbine's apex signifies a thoughtful addition, capturing supplementary electricity. The hybrid energy system thus functions incessantly, day and night, courtesy of the consistent winds generated by the passage of vehicles. This comprehensive setup effectively harmonizes two complementary energy sources to fulfill the ever-increasing demand for power [7].

In essence, this innovative hybrid energy system presents a versatile solution for addressing the evolving energy landscape. By efficiently capturing wind energy from highway traffic and solar energy during the day and night, it serves as a beacon of sustainability, reliability, and cost-effectiveness. As the world grapples with surging energy requirements and the urgency of reducing the environmental footprint, solutions like these stand as a testament to the potential of harmonizing renewable energy resources. The adaptability of this system to various installation sites, coupled with its ability to harness wind and solar power, underscores its role as a promising alternative in the quest for cleaner and more reliable energy solutions. Whether situated on highways, in parks, or amidst residential areas, the impact of such hybrid systems extends beyond mere electricity generation; it offers a holistic approach to addressing today's pressing energy challenges while forging a path towards a more sustainable and environmentally conscious future [8].

Electricity constitutes an indispensable aspect of our daily lives, and with non-renewable energy sources depleting at an alarming rate, it becomes increasingly imperative to transition towards sustainable alternatives for power generation. While renewable sources may yield slightly less electricity compared to conventional options, their most significant advantage lies in their minimal environmental impact. The solar-wind hybrid system effectively merges both solar and

wind energy generation to ensure an uninterrupted power supply. In adverse weather conditions, a microcontroller plays a pivotal role in seamlessly transitioning between these two energy sources [9]. Wind energy is harvested through the rotational motion of windmill blades induced by moving vehicles.

As the demand for electricity continues to soar, the necessity for expanding renewable energy generation becomes increasingly evident. This research paper centres its focus on electricity generation through vertical axis wind turbines (VAWT) powered by the kinetic energy of moving vehicles along highways. The central location of highways serves as the hosting ground for these wind turbines, with particular emphasis placed on vertical axis models. A hybrid VAWT configuration is introduced, which significantly enhances wind energy utilization efficiency through superior drag and lift properties [10]. This innovative hybrid design empowers the turbines to rotate effectively even at low wind speeds, ensuring a consistent power supply. The electricity generated by these VAWTs finds practical application in various highway-related operations, thereby promoting effective energy utilization and contributing to a more sustainable future.

3. System Configuration

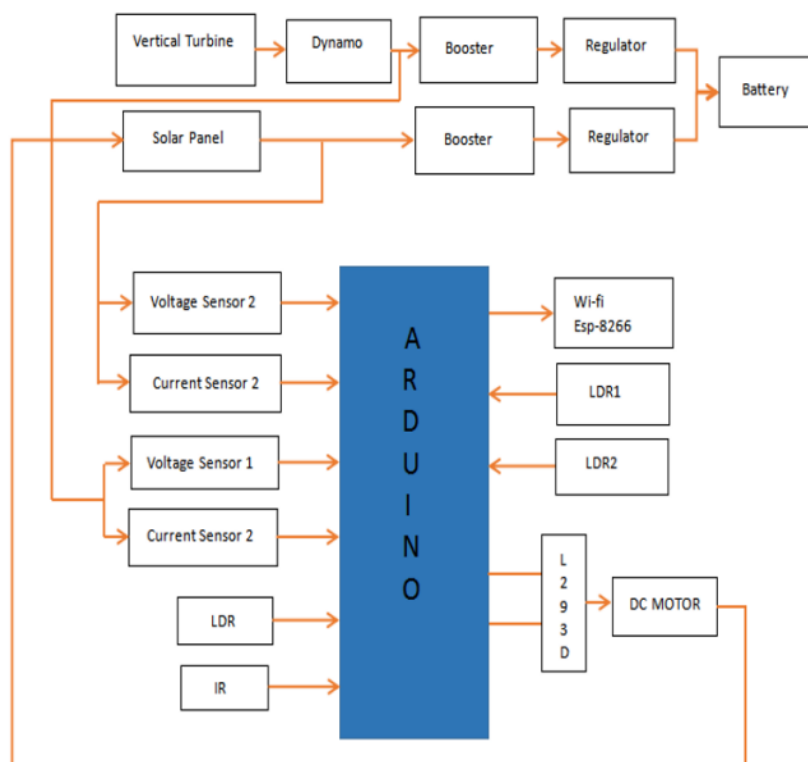


Fig 1. Schematic of Dual Power Generation and Remote Monitoring System for Highways via IoT

As vehicles traverse the highway, they disturb the airflow above the road's surface, creating significant wind turbulence. This wind turbulence, a valuable energy source, sets the windmill's blades in motion, enabling electricity generation. The intensity of this turbulence is closely linked to the size and speed of passing automobiles, as well as the traffic frequency. To harness this energy efficiently alongside a highway, wind turbines capable of utilizing moderate wind speeds are essential. The optimal choice for such an application is Vertical Axis Wind Turbines (VAWT).

In a strategic approach, solar panels are strategically positioned on the highway dividers to harness energy from sunlight during the day and from vehicle headlights during the night. While the accuracy of nighttime energy production may reach around 30-40%, the system's efficiency is further improved through the implementation of a Solar Tracking System. Light Dependent Resistors (LDRs) play a pivotal role in tracking the maximum sunlight. When LDR1 receives maximal light, the solar panel moves clockwise, and vice versa for LDR2. When both sensors receive equal light, the solar panel maintains its position.

The movement of the solar panel is facilitated by a Direct Current (DC) motor, which ensures it stays oriented toward the sun's direction. The control of this DC motor and the management of the entire system are orchestrated by an Arduino, capable of receiving data from voltage and current sensors. It also utilizes a Wi-Fi module to upload the collected data to the cloud. This cloud-stored data is essential for monitoring the power generated by both the solar panels and the wind turbine through a sensor network. This information serves as a valuable resource for future analysis and decision-making.

In the quest for efficient energy utilization, an automatic street light controller has been implemented. This controller optimizes power usage, ensuring that the energy generated is put to practical use. Excess energy that remains unutilized can be stored in batteries for later use. The dual power generation system is an innovative combination of a solar plant and a wind energy plant, each contributing optimally based on seasonal variations. During winter, the system yields maximum output from the wind turbine, while in the summer, the solar panels reach their peak energy production. This flexible and integrated system often presents economic and environmental advantages, outperforming stand-alone wind, solar, geothermal, or trigeneration systems.

4. Advantages

The integrated energy system under consideration represents a remarkable fusion of two diverse yet complementary energy sources, marking a significant stride towards maximizing energy production. With a world witnessing a surge in energy demand, this innovative solution comes as a beacon of reliability, environmental sustainability, and cost-effectiveness. Its versatile design efficiently harnesses wind turbulence, particularly abundant near highways, ensuring an optimal energy yield.

To enhance its effectiveness, the integrated energy system integrates a solar tracking system, a technology that further elevates its energy generation capabilities. This system is engineered to ensure that the solar panels consistently face the sun, adapting to its position throughout the day. What's more, this system doesn't rest when the sun sets; instead, it taps into the illuminating power of vehicle headlights during nighttime hours. This round-the-clock approach to energy generation adds a layer of resilience, making it even more attractive.

In addition to its robust energy generation capabilities, this system excels in the efficient utilization of the produced power. An automatic street light controller is integrated into the system, offering a fine-tuned approach to power consumption. This controller ensures that the energy generated is judiciously directed towards practical applications. In periods of surplus energy, the system doesn't waste it; instead, it capitalizes on energy storage in batteries, creating a reservoir for various purposes, including illuminating streets and powering toll gates.

This comprehensive approach to energy generation, storage, and utilization is a testament to the technology's holistic design. Its impact reaches far beyond merely meeting energy demands; it stands as a practical solution for the globe's growing energy needs. By intelligently harnessing the capabilities of wind and solar energy, it sets a precedent for how the world can transition towards more sustainable, reliable, and environmentally friendly energy solutions. As the systems find applications near highways, in remote areas, and beyond, the integrated energy system's contributions to a greener, more energy-efficient world become increasingly apparent. Its versatility, environmental friendliness, and economic viability make it a standout choice for addressing the pressing energy challenges of our time.

5. Disadvantages

The performance of this energy generation system is notably influenced by climatic fluctuations. Its efficiency is inherently linked to the availability of wind and sunlight, which can vary based on weather conditions and time of day. During periods of low wind speeds or reduced sunlight, the system's energy output may diminish, impacting its reliability as a primary power source. This climatic dependence introduces an element of unpredictability, making it less consistent in meeting energy demands.

Additionally, when compared to non-renewable resources, the overall efficiency of this renewable energy system tends to be lower. Non-renewable resources, such as fossil fuels, can provide a more constant and high-output energy supply, even in adverse weather conditions. However, it's important to consider the environmental advantages of renewable sources, as they offer a cleaner and more sustainable approach to energy production, despite some limitations in efficiency. The trade-off lies between reduced environmental impact and the occasional variability in energy generation associated with renewable systems.

6. Applications

This innovative energy generation system finds its primary application on highways, where the rapid movement of vehicles generates wind turbulence. This wind pressure, caused by the flow of traffic, propels the blades of windmills, effectively harnessing this kinetic energy to produce electricity. The highways present an ideal setting for this technology due to the high-speed vehicle traffic, resulting in a consistent source of energy. This sustainable approach aids in reducing the carbon footprint associated with conventional power generation methods, contributing to a cleaner environment.

Beyond highway applications, this system can also be effectively implemented on the rooftops of residential houses. By doing so, households can tap into the benefits of renewable energy, with the added advantage of relatively low maintenance costs. The electricity generated by these rooftop installations can be efficiently stored in a battery bank, ensuring a reliable power source for various household activities. This stored energy provides a backup power supply during outages or periods of low energy generation, adding an extra layer of reliability to the system. The utilization of

renewable energy not only reduces electricity bills but also demonstrates a commitment to sustainability and environmental responsibility. This versatile technology is adaptable to diverse settings, making it a viable choice for addressing energy needs in both urban and residential environments.

This innovative dual power generation system, which combines wind and solar energy, has a wide range of applications in addition to highways and residential rooftops:

1. **Remote Areas and Off-Grid Locations:** Many remote and off-grid areas lack access to a reliable power supply. This technology can be deployed in such locations to generate electricity for basic needs, such as lighting, charging electronic devices, and powering essential appliances. It ensures a sustainable power source, reducing dependence on fossil fuels and traditional power grids.
2. **Agricultural and Farming Operations:** Farms and agricultural facilities require continuous power for various applications, such as irrigation systems, livestock care, and machinery operation. Integrating dual power generation systems on farms can provide a dependable source of electricity, reducing operational costs and promoting sustainability.
3. **Street Lighting:** Street lighting is a critical aspect of urban infrastructure. The generated power can be employed for street lighting, making cities more energy-efficient and environmentally friendly. The system can be programmed to illuminate the streets when the natural light diminishes.
4. **Emergency and Disaster Relief:** During emergencies, such as natural disasters, power outages are common. Dual power generation systems can serve as reliable backup power sources for critical facilities, shelters, and emergency services, ensuring essential functions continue during challenging times.
5. **Recreational Areas:** Parks, camping sites, and recreational facilities often lack a consistent power supply. These systems can be set up in recreational areas to provide electricity for lighting, charging stations, and other amenities, enhancing the visitor experience and extending the hours of operation.
6. **Residential and Commercial Complexes:** Residential communities and commercial complexes can adopt this technology to reduce their carbon footprint and lower energy costs. These systems can be integrated into the building structure, such as using wind turbines and solar panels on rooftops or in open spaces.
7. **Water Pumping Stations:** Reliable power is crucial for water pumping stations that provide clean drinking water. Dual power generation systems can be used to ensure continuous operation, reducing the risk of water shortages in communities.
8. **Educational Institutions:** Schools and universities can utilize these systems to both generate electricity and educate students about renewable energy technologies. It serves as a practical demonstration of sustainable energy practices.
9. **Sustainable Tourism:** Eco-friendly resorts and tourism destinations can incorporate dual power generation systems to demonstrate their commitment to environmental conservation. Visitors can experience sustainable practices and enjoy the benefits of renewable energy during their stay.

These applications underscore the versatility and importance of dual power generation systems in various contexts, addressing energy needs, reducing carbon emissions, and contributing to a cleaner and more sustainable future.

7. Conclusions

The dual power generation system stands as a formidable and efficient solution for power generation, especially when compared to conventional energy resources. Its advantages extend far beyond increased efficiency, encompassing the ability to bring electricity to remote regions that government infrastructure cannot reach. By scaling up production, considerable cost reductions can be achieved, making this technology accessible to a broader demographic. Encouraging individuals and communities to embrace non-conventional energy resources is paramount, and the dual power generation system sets a shining example.

One of the system's most significant strengths is its environmentally friendly nature. Unlike conventional energy resources, it doesn't emit harmful pollutants or produce toxic waste. This contributes significantly to environmental preservation and mitigates the ecological challenges posed by fossil fuels and nuclear energy.

Wind energy plays a pivotal role in this system, offering a cost-effective, renewable, and green energy resource. When implemented alongside highways, specially designed wind turbines exhibit improved efficiency and bridge the gap between power demand and supply. The turbine's high efficiency doesn't just harness wind from a single direction; it

adeptly utilizes wind turbulence created by passing vehicles. This means that no wind goes to waste, as even the airflow from multiple directions is harnessed.

The wind turbine's design is a testament to its effectiveness. It's self-starting, eliminating the need for additional equipment to initiate its operation. Installation is a breeze, making it a practical choice for both highway and remote applications. Even in regions with varying wind speeds, it performs admirably, ensuring a consistent power supply. In fact, the turbine surpasses other wind turbine types in efficiency, with a 2.75 times greater efficiency than Savonius turbines and a 1.57 times improvement compared to Darrieus turbines. This remarkable efficiency translates to higher energy output for the same amount of wind input, making it an attractive choice for power generation.

In summary, the dual power generation system embodies the transition to cleaner and more sustainable energy solutions. Its efficient wind turbines, combined with the usage of renewable resources, not only fulfill energy needs but also protect the environment. As the world seeks greener alternatives, this system sets a stellar example of what can be achieved when technology and sustainability unite. Its applications are varied, and its potential is limitless, heralding a brighter, cleaner, and more sustainable future for all.

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