A Safe Hybrid Lighting System for Highways Using Renewable Energy Sources

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ABSTRACT

Abstract— The Hybrid Lighting System (HLS) provides safe and reliable illumination for drivers and pedestrians while minimizing the impact on the environment. In this paper, a safe HLS for highways using Renewable Energy Sources (RESs) is designed. This design involved the development of a lighting system that utilizes both solar and wind energy to energize LED lights on highways. The design process incorporated selecting appropriate RESs, designing a system that optimizes energy generation, storage, and integrating it with a reliable HLS that meets safety standards. The implementation encompassed installing the system on highways and testing its performance under various conditions. Testing included evaluating the system's efficiency, reliability, and safety. The performance of the proposed system is assessed by measuring its energy output, lighting intensity, and battery life. The safety of the designed system is evaluated by testing its durability under extreme weather conditions and its ability to withstand impact from vehicles. A novel automated self-cleaning mechanism was developed to maintain the efficiency of solar panels, addressing challenges posed by dust accumulation in desert environments. Overall, the development of a safe HLS for highways using RESs has the potential to reduce the carbon footprint associated with traditional lighting systems while improving the safety of highways for drivers and pedestrians.

Keywords: *Hybrid Lighting System (HLS); Renewable Energy Sources (RESs); Renewable Energy*

I. INTRODUCTION

With the increasing demand for sustainable and eco-friendly solutions, there is a growing need for Renewable Energy Sources (RESs) to energize public infrastructure such as highways. Lighting Systems (LSs) for highways are critical in ensuring safe and efficient transportation at night, but traditional LSs have a significant impact on the environment and consume a substantial amount of energy.

Designing, implementing, and testing a safe Hybrid Lighting System (HLS) for highways using RESs is an innovative solution to address these challenges. This system combines two or more RESs such as solar, wind, and/or hydro power to provide a reliable and sustainable source of energy for highway lighting.

The HLS is designed to ensure safety, efficiency, and reliability while minimizing the environmental impact. The system must be able to operate autonomously and ensure that lighting is consistently provided throughout the night. The implementation of the system requires careful consideration of several factors, including the location of the highway, weather conditions, and power availability.

Testing the effectiveness and efficiency of the HLS is crucial to ensure its competence to withstand different weather conditions, operate seamlessly, and provide sufficient lighting for highway users. The testing phase should involve various tests, including functionality and performance testing, safety testing, and validation testing, among others.

The successful implementation of a safe HLS for highways using RESs can provide numerous benefits, including reducing carbon footprint, lowering energy costs, and improving the safety and efficiency of highways at night. This paper demonstrates a commitment to sustainable development and highlights the potential of renewable energy sources in energizing critical infrastructure [1], [2].

Wind power is a RES that offers various benefits over the non-renewable sources similar to coal and oil. Dissimilar these finite resources, the wind is considered an infinite resource that tin can be harnessed for generating electricity without exhausting the natural resources. Furthermore, Wind-Powered Street Lights (WPSLs) offer a reliable source of power or energy that is not dependent on the volatility of the electricity market. This means towns and cities and count on wind to light streets without supply shortages or changeable energy prices.

WPSL offer a cost-effective different to traditional SL options. Once installed, they will operate as a constant supply of electricity from grid. This means that municipalities will save on costs of energy and reduce the reliance on the grid. With WPSLs, there are no bills of electricity to pay, as the wind turbines generate energy from wind for free. This can improve their bottom line and reduce operating costs.

WPSLs are an environmentally solution for lighting-public spaces. Unlike classical SLs that require energy from non-renewable sources (NRSs), WPSLs harness the wind power to generate clean energy. The WPSLs generate electricity implementing WTs and yield zero-greenhouse gas emissions. They also can reduce the dependence on fossil fuels. WPSLs provide energy independence via harnessing the wind power to generate energy. This energy can be used to PSLs directly or stored in batteries.

These SLs do not depend on the traditional grid, which is powered by the fossil fuels and may subject to power-outages and blackouts. WPSLs require less maintenance and they are more durable since they generate their energy through the use of WTs. The WTs convert wind energy to electrical energy. This energy is stored in batteries. Therefore, an external energy source is not needed, such as the main grid that is expensive to be installed and maintained.

WPSLs are more durable and less susceptible to energy outages and the other electrical issues that occur with classical SLs. In addition, WTs are designed for withstanding harsh weather conditions [3].

A solar street light WT is the landmark invention of wind-solar street lamps. The significant of fan choice is to make fan operate smoothly. The lamppost is greatest careful that the fixing portions of solar support and the lampshade are loose because of the vibration in fan during operation. Another key factor for a fans selection is their beautiful lightweight, reducing tower load, and appearance [4].

This paper proposes a safe HLS for highways using RESs. This design involves the development of a lighting system that utilizes both solar and wind energy to energize LED lights on Sokhna- Hurghda high way. The design process incorporates selecting appropriate RESs, designing a system that optimizes energy generation, storage, and integrating it with a reliable HLS that meets safety standards. The implementation encompasses installing the system on highways and testing its performance under various conditions.

The rest of the paper is organized as follow. Section II presents the description and modelling of HLS. Section III investigates location and case study. Section IV introduces system sizing. Section V introduces experimental setup. The conclusion of the paper is given in Section VI.

II. HLS DESCRIPTION AND MODELLING

The HRE system includes diverse components that can be designated according to the site location, the system type, and the applications. A Balance-of- system that wired to form the whole fully functional-system able to supply electric power. Fig.1 shows the block diagram of the complete HLS. The components of the proposed system will be described in the following subsections:

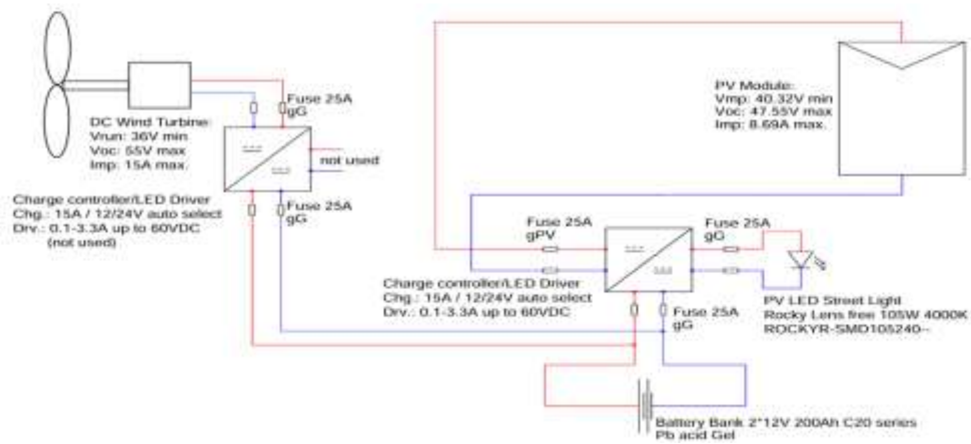

Fig. 1: Block Diagram of the HLS

A. PV Module

The PV module system is the essential part of the wind-solar- based hybrid SLs, and it is the most valuable section of the Solar Street Lamp (SSL). Its function is to transform the solar radiation into electrical energy or store it in the battery. Among various solar cells, polycrystalline-silicon type solar cells, amorphous-silicon type solar cells, and monocrystalline-silicon type solar cells are practical and more common. In areas with good sunshine and enough sunlight, it is better to utilize polysilicon-type solar cells, as the production of polysilicon type solar cells is relatively more simple besides lower price than crystal type solar cells. It is superior to utilize monocrystalline silicon type solar cells in the areas with less sunshine and more rainy days due to the performance parameters of the monocrystalline silicon type solar cells are comparatively stable[5].

B. Automated Self-Cleaning System for PV Panels

In solar energy systems, dust accumulation is a major issue that can reduce panel efficiency by up to 30%. Manual cleaning is not always feasible, especially in remote or large-scale installations. To address this problem, an automated self-cleaning system was developed to maintain optimal panel performance and reduce operational costs. Fig. 2 indicates the dry cleaning mechanism implemented in the solar panel. Fig.3 shows the hardware of the stepper motor, microcontroller, and stepper motor driver implemented in the self-cleaning system

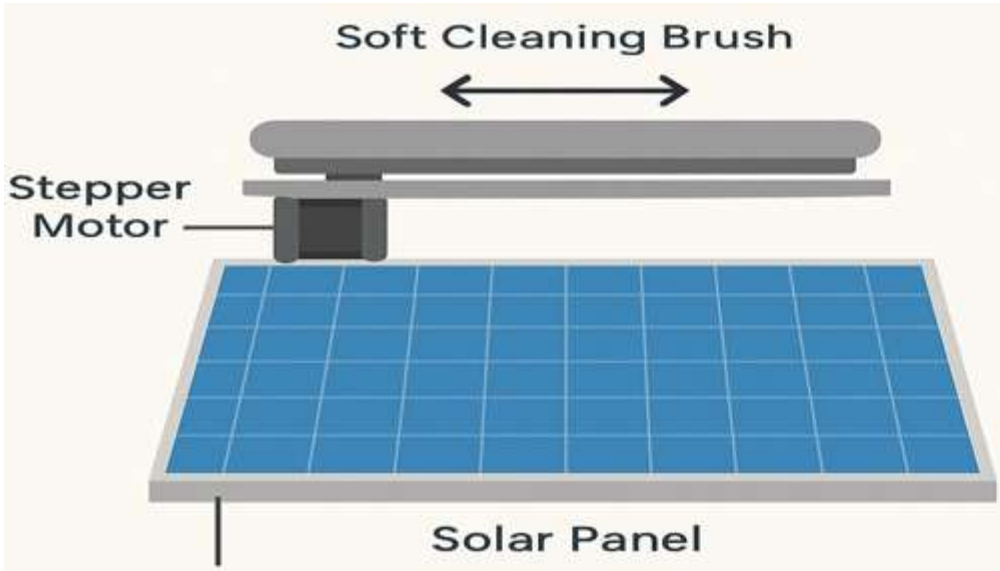

Fig. 2: Dry cleaning mechanism of PV

(a) Stepper motor (b) Arduino uno (c) A4988 stepper motor driver

Fig. 3: Components of self-cleaning system

C. Wind Turbine

The Vertical Axis Wind Turbine (VAWT) is a crucial component of WPSLs. It takes the energy from wind and then converts it into electrical energy to supply the street light. WTT is mounted on the top of the SL pole. It contains a rotor, a blades, and a generator. In accordance with the power of the LS, the power of the WT is different. Generally ranges of 200 W, 300 W, 400 W, 600 W, and so on. The output-voltage has 12 V, 24 V, 36 V, and so on [4]-[9].

D. Battery

As the input energy of solar PV generation system is very unstable, it is usually necessary to configure battery storage system to work. In general, there are lead-acid type batteries Ni-H batteries, colloidal type batteries, and Ni-Cd batteries. However, the market choice of the lithium type has become the mainstream, because of its small size, longer service life, and high efficiency. The choice of capacity follows the following principles: The premise of meeting lighting at the night, energy of PV modules in the daytime that should be stored, and the electrical energy desired for lighting at the night in the continuous rainy days. Battery capacity is too small to meet the needs of night lighting, the battery is too large, on the one hand, the battery is always in a state of power loss, which affects the battery life and causes waste. The battery shall match with a solar cell and electric load (street lamp) [8].

E. Controller

No matter the size of the hybrid street light, a good charge and discharge controller is essential. In order to prolong the service life of the battery, its charging and discharging conditions should be limited to avoid deep charging and overcharge. With a large temp difference, the controller should have a temp compensation function. Also, the PV controller must have a SL control function, time control function, a light control, and an automatic load-switching function at the night, to extend the time of working of street lamps on the rainy days.

F. LED Lights

LED lights are light source in WPSLs. They are very efficient and consume much less energy than the traditional street lights. LED lights may be configured to rotate automatically when the motion is detected or it becomes dark.

G. Pole

The pole offers support for all other components of WPSLs. It is typically made from aluminium or steel and is designed for withstanding strong winds and the other environmental circumstances. The pole houses the controller and the battery and is a mounting point used for the WT and LED lights.

III. LOCATION AND CASE STUDY

The target of the proposed HLS is to install on Sokhna- Hurghda high way. Despite its importance, this road does not have any lighting at night. Fig.4 shows the location of the high way, while .Figures 5 and 6 illustrate the wind speed along one year. Fig. 7 shows the distribution of wind speed, Precipitation and temperature over one year. Figure 8depict the data of cloudy, sunny and precipitation over a year.

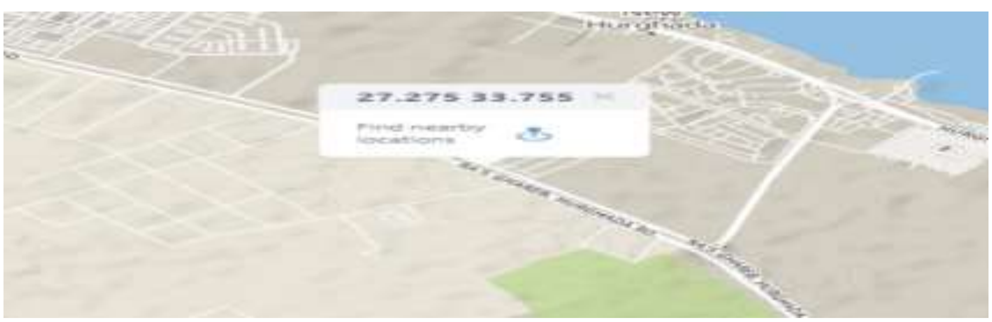

Fig. 4: Location of the Hurghda high way

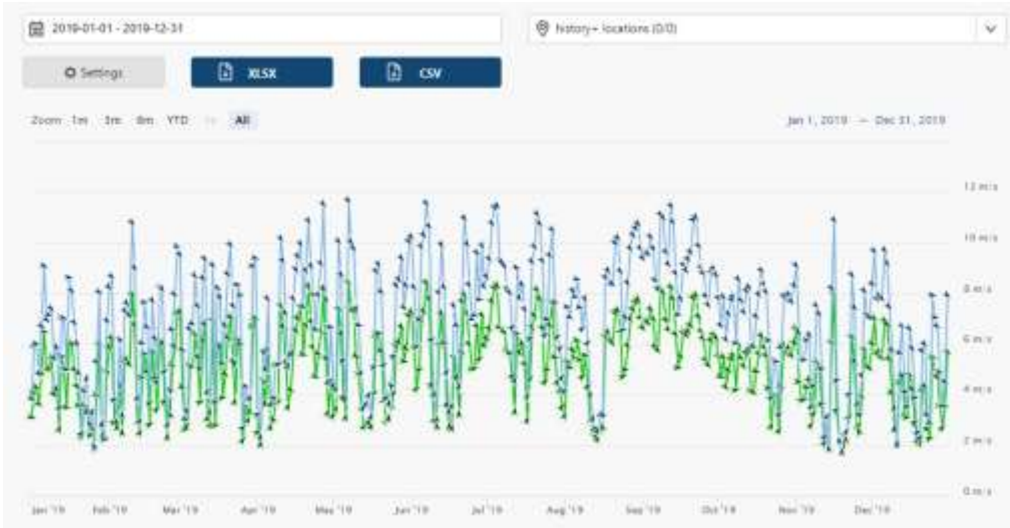

Fig. 5: Wind speed over one year

Fig. 6: Wind speed over one year

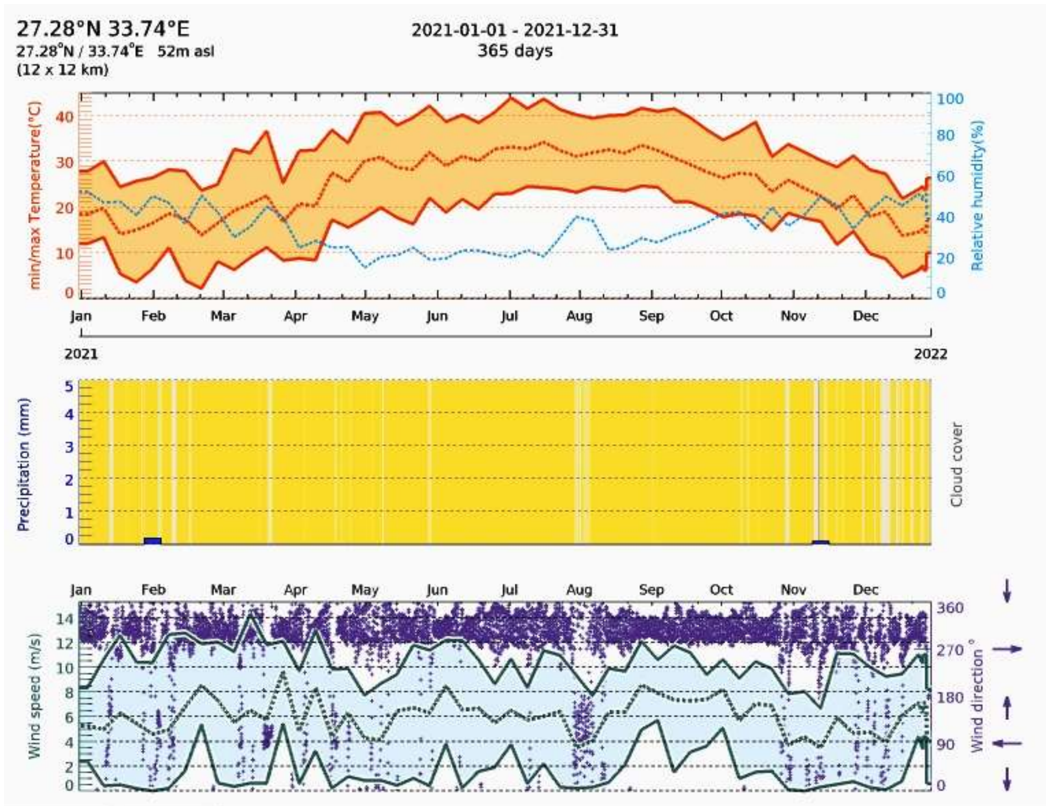

Fig. 7: Temperature, precipitation and wind speed over 2021

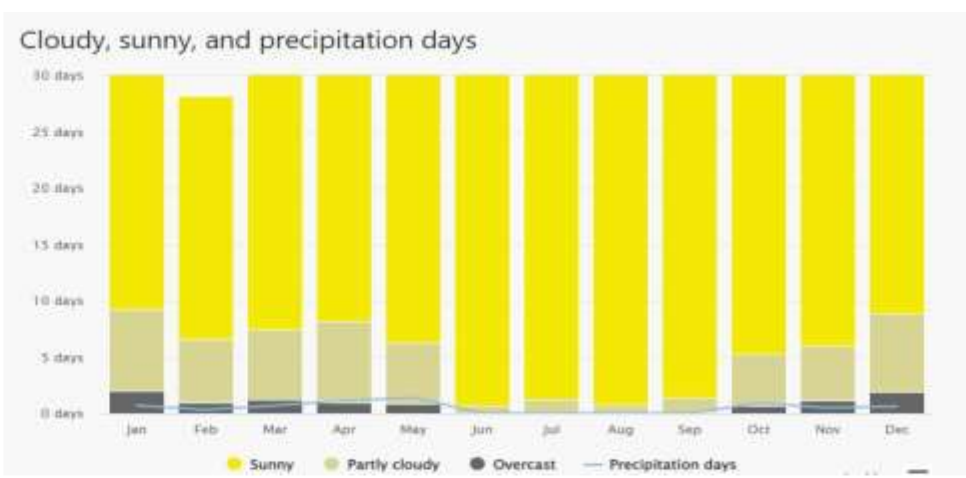

Fig. 8: Data of cloudy, sunny and precipitation over a year

IV. SYSTEM SIZING

The sizing of a hybrid system consisting a PV system and a VAWT to power a lighting projector of 200W for 10 hours with one day of autonomy is presented. The high of light pole is

12 m. The system is designed to achieve a 30 Lux on the high way. The light projector is modified for feeding DC voltage. The following steps is considered for design [6],[7], and [8].

A. Daily Energy Consumption of Lighting Projector

Energy consumption can be estimated according to equation (1). Energy consumption is calculated as 200W x 10 hours or 2 kWh.

Energy consumption = Power x Time (1)

B. Energy Required per Day, Including Losses

Energy required per day can be calculated using equation (2).

Energy required per day = Energy consumption / System efficiency (2)

Assuming a system efficiency of 80%, It is obvious that Energy required per day = 2 kWh / 0.8. This means that energy required per day equals 2.5 kWh.

C. PV Module sizing

The PV size can be designed according equation (3).

$$Size_{pv} = \frac{E_{DHS}(1-Con_{VAWT})}{H_{PS}.\zeta_{module}} \quad (3)$$

Where $Size_{pv}$ is the PV module size, E_{DHS} is the energy required per day from hybrid system, Con_{VAWT} is the VAWT contribution, H_{PS} is Peak sun hours, and ζ_{module} is Module efficiency.

Assuming a VAWT contribution of 40 %, peak sun hours of 7, and module efficiency of 15%, we get:

PV module size = 2.5 kWh x 0.6 / (7 x 0.15) = 1.4 kWp

In this paper, two modules each of which is 500 are selected.

D. Self-cleaning

The cleaning mechanism in this project is based on a dry, automated brushing system. A soft brush mounted on a mobile frame is driven by a stepper motor to travel across the PV panel surface. The system is designed to activate every 15 days using a real-time clock and performs a complete forward and backward sweep with a short pause at each end. This mechanism provides an effective and sustainable solution for maintaining panel cleanliness without the need for water, making it especially suitable for remote or arid regions.

The proposed system uses a combination of mechanical and electronic components, including: Microcontroller, Stepper Motor, and Motor Driver. The practical specifications for the implemented components are indicated in the appendix.

E. VAWT sizing

The VAWT size can be designed according equation (4).

$$Size_{WT} = \frac{E_{DHS}(1-Con_{pv})}{24\ \zeta_{WT}} \quad (4)$$

Where $Size_{WT}$ is the VAWT size, E_{DHS} is the energy required per day from hybrid system, Con_{PV} is the PV contribution, and ζ_{WT} is turbine efficiency.

Assuming a PV contribution of 60 %, a turbine efficiency of 30 %, and 12 hours of operation, we get:

VAWT size = 2.5 kWh x 0.4 / (12 hours x 0.3) = 0.277 kW or 300 W

F. Battery Sizing

The size of the implemented battery can be selected according to equation (5)

Battery size = Energy required per day x Autonomy / Battery efficiency x Depth of discharge (5)

Assuming a battery efficiency of 80% and a 1-day autonomy, and Depth of discharge 60 %

It is found that: Battery size = 2 kWh / 0.6 x 0.8 = 4.2 kWh

Battery Ampere Capacity (BAC) = Battery Size/ Nominal Voltage(NV)

BAC = 4.2 kWh /24 = 174 A

G. Controller Sizing

In this paper, three charge controllers were used, one for each of the two solar PV modules and the third for the combined wind turbine. For solar PV module, the following equations present the calculations of voltage and current of the PV charge controller, which included the maximum power of PV module that is 500 Watt, the maximum voltage of PV module that is 30 V, and the maximum current for the PV module that is 20.8 Ampere. The open circuit voltage of the PV module is 30.4 Volts, and the short current circuit for the PV module is 22.85 Ampere. Then the size of controller is calculated according the following formula [10].

CCC = (NS)(SCC)(LF) (6)

Where CCC is the charge controller current, NS is Number of strings,SCC is the short circuit current, and LF is the average losses.

CCC = (1) (22.8) (1.3) = 29.64 Ampere

Therefore, the charge controller should be rated at 30 Ampere at the 24 Volts. For the wind turbine, based on data on a 300 W catalogue of vertical axis wind turbine, the charge controller voltage is 24 volts, whilst the open circuit current is less than 30 Ampere.

A charge controller is used in this system to provide protection for the lithium-ion battery used to store electrical energy. Charge controller can prevent battery from high level of depth of discharge (DOD), and high level of state of charge (SOC), which can help maintain high lifespan of the battery[11]-[13] . The charge controllers used in this study for both solar PV modules and the VAWT are shown in Figures 9 and 10.

Finally, complete content and organizational editing before formatting. Please take note of the following items when proofreading spelling and grammar:

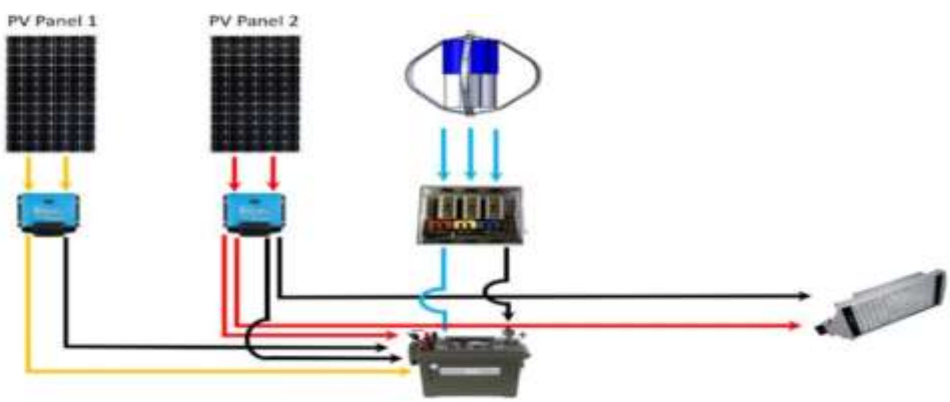

Fig. 9: Construction of PV-Wind street lighting system

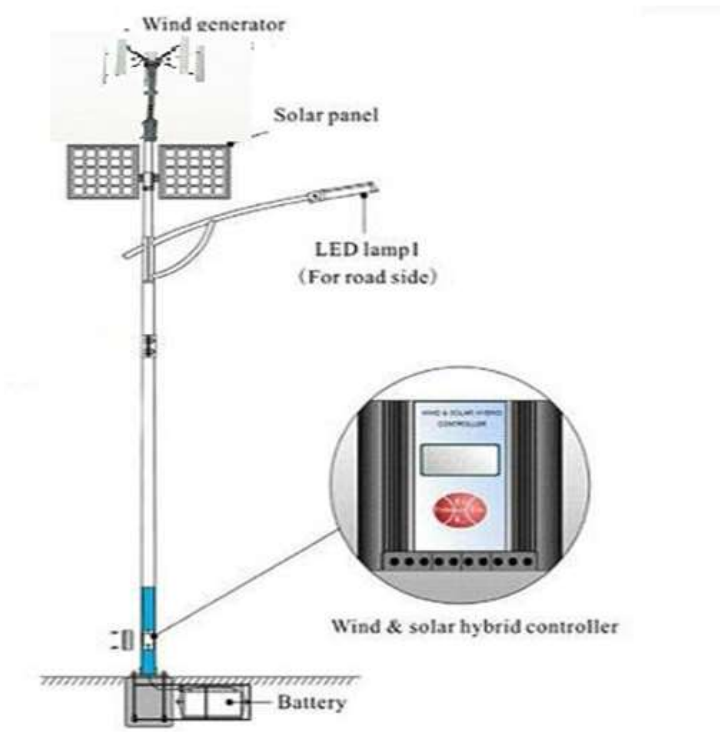

Fig. 10: Hybrid solar/wind street lighting system [13].

V. EXPERIMENTAL SETUP

Figures 11 (a) shows the self-cleaning mechanism implemented in the practical system. The practical VAWT used in the selected site is indicated in Fig. 11 (b). The overall practical HLS is indicted in Fig.12.

(a) PV module

(b) Vertical axis wind turbine

Fig. 11: Practical PV module

Fig. 12: Site-Implemented HLS

VI. CONCLUSION

In conclusion, the design of a safe HLS for highways using renewable energy sources is a viable solution for providing reliable and sustainable lighting to highways. The HLS combines both solar and wind energy sources to power LED lights on highways, reducing the carbon footprint associated with traditional lighting systems and minimizing the impact on the environment. The design process involves selecting appropriate renewable energy sources, designing a system that optimizes energy generation and storage, and integrating it with a reliable lighting system that meets safety standards. The implementation involves installing the system on highways and testing its performance under various conditions. Testing involves evaluating the system's efficiency, reliability, and safety. The system's performance is assessed by measuring its energy output, lighting intensity, and battery life. The safety of the system is evaluated by testing its durability under extreme weather conditions and its ability to withstand impact from vehicles. Overall, the development of a safe hybrid lighting system for highways using renewable energy sources has the potential to reduce the carbon footprint associated with traditional lighting systems while improving the safety of highways for drivers and pedestrians. It is a promising solution for providing reliable and sustainable lighting to highways without relying on fossil fuels.

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APPENDIX:

Arduino Uno

9 January 2025 - 0 Comments

Arduino Uno | Arduino Uno Pinout

Arduino Uno is a popular microcontroller development board based on 8-bit ATmega328P microcontroller. Along with ATmega328P MCU IC, it consists of other components such as crystal oscillator, serial communication, voltage regulator, etc. to support the microcontroller. This article explores the **Arduino UNO pin diagram** in detail along with basics on how to use this board and upload your first code.

NEMA 17 Stepper Motor

19 August 2019 - 0 Comments

NEMA 17 Stepper Motor | NEMA 17 Stepper Motor Pinout

NEMA 17 is a **hybrid stepping motor** with a 1.8° step angle (200 steps/revolution). Each phase draws 1.2 A at 4 V, allowing for a holding torque of 3.2 kg-cm. NEMA 17 Stepper motor is generally used in Printers, CNC machines and Laser Cutters.

Motor Driver: A4988 Module

Key Specifications of a Typical NEMA 17 Stepper Motor:

Parameter	Value
Step Angle	1.8° (200 steps/rev)
Holding Torque	40 N·cm (varies by model)
Operating Voltage	2V – 12V (depends on model)
Current Rating	1.2A – 2A per phase
Shaft Diameter	5 mm
Wiring	Usually 4 or 6 wires (bipolar/unipolar)

Key Features of the A4988 Driver:

Feature	Description
Voltage Supply	8V to 35V
Motor Current Output	Up to 2A per coil (with heat sink and cooling)
Micro stepping	Supports full step, half, 1/4, 1/8, and 1/16 step modes

Feature	Description
Control Pins	STEP and DIR pins control step pulses and direction
Current Limiting	Adjustable via onboard potentiometer
Protection	Built-in over-temperature, over-current, and under-voltage
Size	Very small (20 mm x 15 mm), fits easily in compact systems