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Hybrid Energy Accumulating System for Smart Highway Sustainability

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Abstract - This project presents an innovative **solar-wind hybrid lighting system** for highways, integrating **motion detection sensors** to optimize energy efficiency and enhance road safety. The system utilizes **solar panels** and **wind turbines** to generate electricity, ensuring a continuous and sustainable power supply. Energy harvested from these renewable sources is stored in **battery units**, allowing for uninterrupted operation even during low sunlight or wind conditions. The lighting system is equipped with **motion detection sensors** that detect approaching vehicles and activate LED lights only when needed within a specific radius, significantly **reducing unnecessary power consumption, minimizing light pollution, and extending battery life**. By leveraging a hybrid energy approach, the system ensures **reliability and efficiency**, overcoming the limitations of standalone solar or wind power solutions. The integration of high**-efficiency LED lighting** further enhances energy savings, while the use of smart **sensors** optimizes power utilization by preventing continuous illumination when roadways are unoccupied. This self-sustaining infrastructure eliminates the dependence on fossil-fuel-based electricity, thereby reducing **greenhouse gas emissions and overall energy costs**. Additionally, the reduction in light pollution helps maintain ecological balance and contributes to a healthier nighttime environment. The **cost-effectiveness** of this system makes it an attractive solution for governments and private entities looking to modernize highway lighting infrastructure with minimal maintenance and operational expenses. By aligning with **global sustainability efforts**, this project not only addresses the urgent need for **energy-efficient highway lighting** but also serves as a practical step towards **mitigating climate change and fostering environmental responsibility**.

***Keywords*:** Wind turbine, Solar panels, Hybrid, Greenhouse emissions, LED, etc.,

1. INTRODUCTION:

The enhancement of renewable energy is crucial for present and future environmental sustainability, and one effective approach is the integration of a **hybrid wind-solar system** with **Arduino Uno-based motion detection sensing**. Highways serve as an ideal location for such a system due to their **abundant solar radiation and strong wind currents**, particularly on open plains where wind velocity is high, and solar exposure is maximized. By utilizing both **solar panels** and **Vertical Axis Wind Turbines (VAWTs)**, continuous energy generation can be ensured, as VAWTs are more compact and better suited for urban and roadside environments compared to **Horizontal Axis Wind Turbines (HAWTs)**, which, although more efficient, are impractical for residential or highway settings due to space and noise constraints. The **Arduino Uno microcontroller** plays a key role in managing **energy flow, load distribution, and sensor data processing**, ensuring optimal power utilization and system automation. The incorporation of **motion detection sensors** allows the system to **activate lighting only when necessary**, further enhancing energy efficiency and sustainability. This smart hybrid energy solution not only promotes **renewable energy utilization** but also contributes to **cost savings, reduced environmental impact, and improved highway safety**, making it a **viable and eco-friendly** alternative for modern infrastructure development.

2. WIND AND SOLAR ENERGY HYBRID SYSTEM:

The Solar-Wind Hybrid System is a revolutionary renewable energy system that combines the benefits of solar and wind power to generate electricity. This system is designed to provide a reliable and efficient source of energy for highway lighting, reducing greenhouse gas emissions and mitigating climate change. The Solar-Wind Hybrid System is a groundbreaking renewable energy solution that synergistically integrates solar and wind power to generate electricity, providing a reliable and efficient source of energy for highway lighting. By harnessing the complementary nature of solar and wind energy, this innovative system optimizes energy production and storage, minimizing energy waste and reducing environmental impact. The system's advanced hybrid controller plays a crucial role in ensuring seamless integration of the solar and wind systems, predicting energy demand, and adjusting energy production accordingly. Furthermore, the system's battery bank stores excess energy generated by the solar and wind systems, providing a stable power supply during periods of low energy production. With its cutting-edge technology and sustainable design, the Solar-Wind Hybrid System offers a compelling solution for highway lighting, reducing greenhouse gas emissions and mitigating climate change while providing a reliable and efficient source of energy. By embracing this innovative technology, we can accelerate the transition to a low-carbon economy, promoting a sustainable future for generations to come.

3. WORKING MODEL:

The proposed system offers a sustainable, reliable, and cost-effective solution for highway lighting, contributing to a reduction in greenhouse gas emissions and fossil fuel dependence. The proposed Hybrid Energy Harvesting System integrates a Vertical Axis Wind Turbine (VAWT) and a solar tracker to capture renewable energy efficiently. Unlike conventional systems, this design uses an Arduino microcontroller to dynamically control energy flow, adjusting the wind turbine and solar panel angles based on real-time data. A DC-DC chopper is employed to regulate voltage, ensuring maximum power transfer to the storage units.

For energy storage, the system uses a combination of supercapacitors for rapid charge-discharge cycles and batteries for long-term energy storage, reducing stress on the battery and extending its lifespan. A relay-based switching mechanism intelligently manages load distribution, protecting components from overvoltage or undervoltage.

The innovation lies in the Machine Learning (ML) algorithm that predicts solar. intensity and wind speeds using historical data and weather forecasts. This AI-driven approach optimizes the turbine's rotation speed and solar panel orientation for maximum energy harvesting.

Real-time monitoring is enabled through IoT integration, allowing users to track power output, battery status, and environmental conditions remotely via cloud platforms. An LCD display provides on-site data visualization, enhancing user interaction and system transparency.

A DC geared motor acts as the load, simulating practical applications such as driving small machines or water pumps, proving the system's real-world feasibility. This AI-powered, IoT-connected hybrid system offers a sustainable and efficient solution to renewable energy harvesting, overcoming the limitations of standalone or manually operated systems.

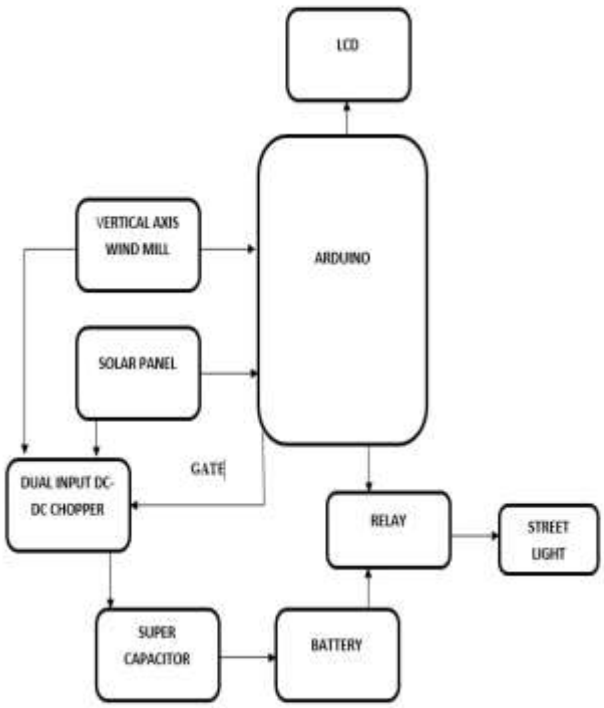

Fig-1: Block diagram of Working Model.

4. HARDWARE REQUIREMENTS:

4.1 VERTICAL AXIS WIND TURBINE (VAWT):

A Vertical Axis Wind Turbine (VAWT) is a type of wind turbine where the main rotor shaft is set perpendicular to the ground. Unlike horizontal axis wind turbines (HAWTs), which require the wind to come from a specific direction, VAWTs can harness wind energy from any direction, making them suitable for urban and complex wind environments.

Wind energy is one of the fastest-growing renewable energy sources, and **Vertical Axis Wind Turbines (VAWTs)** present an innovative alternative to traditional Horizontal Axis Wind Turbines (HAWTs). Unlike their horizontal counterparts, VAWTs have blades that rotate around a vertical axis, allowing them to capture wind from any direction. This makes them highly versatile for urban and off-grid applications.

Vertical Axis Wind Turbines offer a promising alternative to traditional wind turbines, especially for urban and small-scale applications. While they have some efficiency limitations, their ability to work in diverse wind conditions and their ease of maintenance make them an attractive option for sustainable energy solutions.

VAWTs operate by converting wind energy into mechanical power through two primary aerodynamic principles:

- **Lift-based designs** (like the Darrieus turbine) rely on air foil-shaped blades that create a pressure difference to generate rotation.

- **Drag-based designs** (like the Savonius turbine) use curved blades that catch the wind, similar to how a cup anemometer works.

4.1.1 ADVANTAGES OF VAWTS

- ❖ **Omnidirectional Wind Capture** – No need for complex yaw mechanisms.
- ❖ **Compact & Space-Efficient** – Suitable for urban rooftops and tight spaces.
- ❖ **Lower Noise & Visual Impact** – More aesthetic and less disruptive.
- ❖ **Easier Maintenance** – Key components are closer to the ground.
- ❖ **Bird-Friendly** – Lower rotational speeds reduce wildlife hazards.

4.2 ARDUINO UNO

The **Arduino Uno** is a widely used **open-source microcontroller board** based on the **ATmega328P** chip, known for its versatility, ease of use, and affordability. What makes the Arduino Uno unique is its **plug-and-play functionality**, allowing beginners and experts to develop embedded systems with minimal setup. Its **compact design** features **14 digital input/output pins** (6 of which can be used as PWM outputs) and **6 analog inputs**, making it highly adaptable for **sensor integration, automation, and IoT applications**. Unlike other microcontrollers, the Arduino Uno supports **direct USB connection**, eliminating the need for external programmers and simplifying data transfer.

One of its most distinct features is its **open-source hardware and software ecosystem**, providing a vast library of pre-built functions, extensive documentation, and a strong global community that continuously contributes to its development. The **Arduino IDE (Integrated Development Environment)** supports C and C++, with built-in libraries for seamless sensor interfacing, making it ideal for **motion detection, robotics, energy management, and smart automation**. Additionally, its **low power consumption**, **5V operating voltage**, and ability to be powered via **USB or external power sources (7-12V)** make it suitable for portable and battery-operated projects.

A standout feature of the Arduino Uno is its **interrupt-driven processing**, which allows real-time responses to sensor inputs, enhancing efficiency in applications like **renewable energy systems, smart lighting, and automation**. Its capability to interface with **Wi-Fi (ESP8266/ESP32), Bluetooth, and IoT cloud platforms** further extends its functionality into remote monitoring and smart energy management systems. The **durability, affordability, and ease of prototyping** make the Arduino Uno an essential microcontroller for both beginners and professionals in fields such as **renewable energy, robotics, industrial automation, and smart infrastructure**.

4.3 SOLAR PANEL WITH TRACKER:

Solar energy is one of the most reliable and sustainable power sources, but traditional fixed solar panels have limitations in capturing sunlight efficiently throughout the day. Solar panels with trackers solve this problem by dynamically adjusting their position to follow the sun, significantly increasing energy output.

A solar tracker is a mechanical system that moves solar panels to optimize their orientation relative to the sun. By continuously adjusting the angle, trackers help maintain optimal sunlight exposure, reducing energy losses due to the sun's movement.

Solar panels with trackers provide a game-changing solution for maximizing solar energy efficiency. While they come with higher upfront costs, their ability to significantly boost energy production makes them a worthwhile investment, especially for large-scale and commercial projects. As technology evolves, solar trackers will play a crucial role in the transition to a more sustainable and energy-efficient future.

4.4 DC-DC CHOPPER (BOOST/BUCK CONVERTER)

A **DC-DC chopper** is a power electronic device that converts direct current (DC) from one voltage level to another. It plays a crucial role in applications such as electric vehicles, renewable energy systems, and power supplies. The two most common types of DC-DC choppers are:

- **Boost Converter** (Step-Up) – Increases the input voltage.

- **Buck Converter** (Step-Down) – Decreases the input voltage.

These converters ensure efficient voltage regulation and power management across various electronic and electrical applications.

4.4.1 Boost Converter (Step-Up Chopper)

A boost converter steps up the input voltage to a higher output voltage using an inductor, a diode, a switch (MOSFET/IGBT), and a capacitor.

4.4.1.1 Operating Principle:

- **Switch ON** – The inductor stores energy from the power source.

- **Switch OFF** – The stored energy is released, adding to the input voltage and boosting the output voltage.

The output voltage is given by:

$$V_{out} = \frac{V_{in}}{1 - D}$$

Where

- Vout = Output Voltage.
- Vin = Input Voltage.
- D = Duty Cycle (0 < D < 1)

A higher duty cycle results in a greater voltage boost.

4.4.2 Buck Converter (Step-Down Chopper)

A buck converter steps down the input voltage to a lower output voltage using an inductor, a diode, a switch (MOSFET/IGBT), and a capacitor.

4.4.2.1 Operating Principle:

- **Switch ON** – The inductor stores energy while powering the load.
- **Switch OFF** – The stored energy in the inductor continues to power the load through the diode.

The output voltage is given by:

$$Vout = Vin \times D$$

Where **D** is the duty cycle. A lower duty cycle results in a greater voltage reduction.

Table-1: Boost vs. Buck Converter: A Comparison

Feature	Boost Converter	Buck Converter
Function	Steps up voltage	Steps down voltage
Output Voltage	Higher than input	Lower than input
Efficiency	Typically 85-95%	Typically 85-98%
Applications	Renewable energy, EVs, power supplies	Consumer electronics, motor drives, chargers

4.5 SUPERCAPACITOR

A supercapacitor, also known as an ultracapacitor or electric double-layer capacitor (EDLC), is a high-capacity energy storage device that stands out due to its rapid charging and discharging capabilities, long lifespan, and high power density. Unlike traditional batteries, which store energy through chemical reactions, supercapacitors store energy electrostatically, allowing them to deliver bursts of power within seconds.

One of the most unique aspects of supercapacitors is their exceptionally high cycle life, often exceeding 1,000,000 charge-discharge cycles, compared to lithium-ion batteries, which typically last 500–3000 cycles. This makes them ideal for applications requiring frequent and rapid energy exchanges, such as regenerative braking in electric vehicles (EVs), renewable energy systems, and backup power supplies. Additionally, supercapacitors have an extremely low internal resistance (ESR), enabling ultrafast charging (in seconds or minutes) and efficient energy delivery with minimal heat generation.

Another key feature is their wide operating temperature range, typically between -40°C to +85°C, making them more robust than conventional batteries in extreme environments. Unlike batteries, which degrade over time due to chemical aging, supercapacitors maintain their performance without significant capacity loss, reducing maintenance costs and improving reliability.

Supercapacitors are also unique in their ability to bridge the gap between capacitors and batteries, offering higher energy storage than traditional capacitors while providing much faster power delivery than batteries. Their environmentally friendly composition, often free from toxic heavy metals, enhances their appeal for sustainable energy solutions. These properties make them invaluable in applications like solar-wind hybrid systems, electric transportation, industrial power backup, and wearable electronics, where instantaneous power delivery, long lifespan, and high efficiency are crucial.

4.5.1 Mathematical Formulas for Supercapacitors

(a) Capacitance Formula

The capacitance of a supercapacitor is given by:

$$C = \frac{\varepsilon_r \varepsilon_o A}{d}$$

where:

- C = Capacitance (Farads, F)
- εr = Relative permittivity of the dielectric
- εo= Permittivity of free space (8.854×10^{-12} F/m)
- A = Surface area of electrodes (m²)

- d = Distance between electrodes (m)

(b) Energy Stored In a supercapacitor

$$E = \frac{1}{2}CV^2$$

where:

- E = Energy stored (Joules, J)
- C = Capacitance (Farads, F)
- V = Applied voltage (Volts, V)

(c) Charging and Discharging Equations

The voltage across a supercapacitor during charging follows:

$$V(t) = V\,max\left(1 - e^{-\frac{1}{Rc}}\right)$$

The discharge voltage follows:

$$V(t) = V\,max\left(e^{-\frac{1}{Rc}}\right)$$

where:

- Vmax = Maximum voltage (V)
- R = Equivalent series resistance (ESR, Ω)
- C = Capacitance (F)
- t = Time (s)

(d) Time Constant (τ)

The time constant determines how quickly the capacitor charges or discharges:

τ=RC

where:

- τ = Time constant (seconds, s)
- R = Resistance (Ω)
- C = Capacitance (F)

A supercapacitor reaches **63.2% of its full charge** after **one time constant** and is considered fully charged after approximately **5τ**.

(e) Power Output

Instantaneous power delivered by a supercapacitor is given by:

$$P = \frac{V^2}{4R}$$

where:

- P = Power (Watts, W)
- V = Applied voltage (V)
- R = Equivalent series resistance (Ω)

4.6 RELAY MODULE:

A relay module is an essential component in automation, electrical control, and safety systems, providing a reliable method for controlling high-power devices using low-voltage signals. With its ability to interface with microcontrollers, IoT devices, and industrial circuits, the relay module remains a versatile, cost-effective, and indispensable tool for modern electronics and power management systems.

A relay module is an electromechanical device that allows low-power control circuits (such as microcontrollers) to switch high-power loads like motors, lights, heaters, or industrial equipment. It acts as an electrically operated switch, using a small control voltage (e.g., 5V from an Arduino or Raspberry Pi) to control a high-voltage circuit (e.g., 110V or 220V AC devices).

4.6.1 Components.

A typical **relay module** consists of the following key components:

- **Electromagnetic Coil**: A copper coil that generates a magnetic field when energized, pulling the switch contacts together.
- **Common (COM) Terminal**: The main connection point of the switch.
- **Normally Open (NO) Terminal**: The default **off** state; when activated, it connects to COM.
- **Normally Closed (NC) Terminal**: The default **on** state; when activated, it disconnects from COM.
- **Diode Protection Circuit**: Prevents voltage spikes when the coil is turned off.
- **Transistor Driver Circuit**: Used to amplify signals from low-power microcontrollers.
- **Indicator LED**: Shows the relay's **ON/OFF status** for user convenience.

4.6.2 Working Principle:

1. When a **small control voltage** is applied to the relay module, current flows through the **electromagnetic coil**, generating a magnetic field.
2. This magnetic field attracts the **relay switch**, changing its state from **normally open (NO) to closed** (or from **normally closed (NC) to open**).
3. This switching mechanism allows a **low-voltage signal** to control **high-power electrical devices** safely.

4.6.3 Mathematical Formulas for Relay Modules

(a) Coil Power Consumption

The power required to activate a relay coil is:

P=V×I

where:

- P = Power (Watts, W)
- V = Coil voltage (Volts, V)
- I = Coil current (Amperes, A)

For example, if a **5V relay** draws **70mA**, its power consumption is:

$$P = 5V \times 0.07A = 0.35W$$

(b) Contact Rating Calculation

The relay's **contact current capacity** must exceed the load's power requirements:

$$I = \frac{P}{V}$$

where:

- I = Load current (Amps, A)
- P = Power of the device (Watts, W)
- V = Operating voltage (Volts, V)

For example, a **100W bulb at 220V** requires:

$$I = \frac{100W}{220V} = 0.45A$$

Thus, a **relay rated at 1A or more** is sufficient.

(c) Relay Switching Time

The response time (t) of an electromechanical relay depends on coil resistance R and inductance L:

$$t = \frac{L}{R}$$

where:

- L = Coil inductance (H)
- R = Coil resistance (Ω)

Lower inductance leads to **faster switching** speeds.

4.7 VOLTAGE AND CURRENT SENSORS (INA219 OR ACS712):

Voltage and current sensors play a crucial role in power monitoring, energy management, and system protection in electrical and electronic circuits. Two widely used sensors for measuring voltage and current are the INA219 and ACS712, each offering unique advantages depending on the application.

4.7.1 INA219: High-Precision Voltage and Current Sensor:

The **INA219** is a **bi-directional, high-accuracy power sensor** that measures **both voltage and current**, making it ideal for **battery monitoring, power optimization, and energy-efficient IoT applications**.

4.7.1.1 Key Features of INA219

- ❖ **I2C Interface** – Communicates using an **I2C protocol**, allowing easy integration with microcontrollers like **Arduino, ESP32, and Raspberry Pi**.
- ❖ **High Precision** – Measures **current up to ±3.2A** and voltage up to **26V** with **16-bit resolution**.
- ❖ **Shunt Resistor Integration** – Uses an **internal 0.1Ω shunt resistor** to measure voltage drops and calculate current.
- ❖ **Bi-Directional Current Sensing** – Can measure **both charging and discharging currents**, useful for **battery and solar applications**.
- ❖ **Low Power Consumption** – Ideal for energy-efficient applications, consuming minimal power.

4.7.1.2 Working Principle of INA219

- The sensor measures **voltage drop** across an **internal precision shunt resistor (0.1Ω)**.
- Ohm's Law is used to determine current:

$$I = \frac{Vshunt}{Rshunt}$$

where:

- ○ I = Current (A)
- ○ Vshunt = Voltage drop across the shunt resistor (V)
- ○ Rshunt = Shunt resistor value (Ω)

The power consumption of a load is calculated as:

P=V×I

4.7.2. ACS712: Hall-Effect Based Current Sensor

The **ACS712** is a **Hall-effect current sensor** designed to measure **AC and DC currents**, making it highly versatile for **power monitoring, motor control, and industrial automation**.

4.7.2.1 Key Features of ACS712

- **Hall-Effect Technology** – Uses **magnetic fields** to measure current, ensuring **non-intrusive and isolated sensing**.
- **Wide Current Range** – Available in **5A, 20A, and 30A** variants.
- **Analog Output** – Provides a **linear voltage output** proportional to current.
- **High Isolation** – Electrically isolates the measured circuit from the control system.
- **Fast Response Time** – Suitable for **real-time power monitoring applications**.

4.7.2.2 Working Principle of ACS712

- **Hall-effect sensing** is used to measure current without direct contact.
- The sensor outputs an **analog voltage**, which varies linearly with the current.

The output voltage is given by:

$$V_{out} = V_{zero} + (Sensitivity \times I)$$

where:

i. Vout = Output voltage (V)
ii. Vzero = Zero current voltage (typically **2.5V** for bidirectional sensors)
iii. **Sensitivity** = Sensor's sensitivity (e.g., **185mV/A for ACS712-5A**)
iv. I = Measured current (A)

Table – 2 Comparison: INA219 vs ACS712

Feature	INA219	ACS712
Measurement Type	**Voltage & Current**	**Current Only**
Technology	**Shunt Resistor**	**Hall-Effect Sensor**
Current Range	**Up to ±3.2A**	**5A, 20A, 30A models available**
Voltage Measurement	**0–26V**	(Not supported)
Output Type	**Digital (I2C)**	**Analog (Voltage output)**
Accuracy	**High (16-bit precision)**	**Moderate (depends on interference & calibration)**
Bidirectional Current Sensing	Yes	Yes
Isolation	No (Direct measurement)	Yes (Magnetic isolation)
Best For	**Battery monitoring, low-power applications**	**AC/DC current sensing, motor control, industrial use**

5. FINAL OUTPUT:

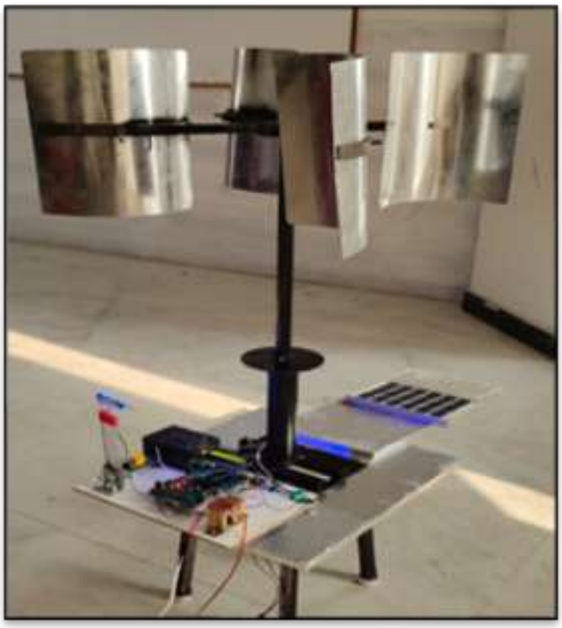

Fig-2: Working Model kit.

The above picture which represents the Smart Highway Dual Energy Harvesting System. The system which hybrids the solar and wind energy for power generation. The generated power is used to operates the highways lights. And also, the system contains the Arduino uno for motion sensing (i.e) the sensor will detect any vehicle which under the radius of the sensing unit then the highways light were turn ON, after the vehicle passes then automatically the light were turn OFF after few seconds. This system provides the enhancement of renewable energy and also save the power by turn off the light which ON at whole night.

6. FUTURE SCOPE OF THE PROJECT

The proposed **solar-wind hybrid highway lighting system with motion detection** presents a **sustainable and energy-efficient** solution for smart infrastructure. However, future advancements can enhance its efficiency, reliability, and scalability.

Integration with IoT and Smart Monitoring:

- Implementing **IoT-based remote monitoring** can enable real-time tracking of **energy generation, consumption, and system health**.
- Cloud-based analytics can optimize energy use and **predict maintenance requirements**.

AI-Based Adaptive Lighting:

- **Machine learning algorithms** can analyze traffic patterns and **dynamically adjust lighting intensity** to minimize energy waste.
- AI can also **predict weather conditions** to optimize solar and wind energy utilization.

Enhanced Renewable Energy Storage:

- Using **supercapacitors along with batteries** can improve **energy storage efficiency** and **extend battery life**.
- Hybrid storage solutions can **ensure uninterrupted power supply** during low-wind or low-sunlight conditions.

Advanced Motion Sensing Technologies:

- **Radar-based sensors and thermal imaging** can enhance vehicle detection accuracy, ensuring **reliable lighting control** even in extreme weather conditions.
- Vehicle speed detection can be integrated for **intelligent traffic monitoring and safety improvements**.

Wireless Power Transmission:

- Exploring **inductive or microwave power transfer** can eliminate the need for underground cabling, reducing installation and maintenance costs.

Smart Grid Connectivity:

- The system can be integrated with **smart grids**, allowing excess energy to be fed into the **national power grid**, making highways an **active energy contributor**.

Expansion to Smart City Infrastructure:

- The same hybrid power system can be applied to **smart traffic signals, electric vehicle charging stations, and urban street lighting**.
- Integration with **5G and intelligent transport systems (ITS)** can enhance urban connectivity.

Self-Healing and Predictive Maintenance:

- AI-based diagnostics can detect faults in the **solar panels, wind turbines, or sensors**, enabling **predictive maintenance** to prevent system failures.

By implementing these **future innovations**, the system can evolve into a **fully autonomous, self-sustaining, and highly efficient** smart energy solution, aligning with global **sustainability and climate action goals**.

7. CONCLUSION: The integration of wind and solar energy harvesting systems offers a promising solution for efficient and reliable renewable energy generation. The dual-source hybrid system mitigates the intermittency of individual renewable energy sources, enhancing overall system performance and energy yield. Simulation results demonstrate the potential of wind-solar hybrids to optimize energy production, reduce power fluctuations, and increase system efficiency. wind-solar hybrid systems offer a compelling solution for efficient, reliable, and sustainable renewable energy generation. As technology continues to evolve and costs decrease, these systems are poised to play a vital role in the global transition to a low-carbon energy future.

The proposed **solar-wind hybrid highway lighting system with motion detection** offers an innovative, sustainable, and energy-efficient solution for modern infrastructure. By harnessing **solar and wind energy**, the system ensures a **reliable and continuous power supply**, reducing dependence on fossil fuels and minimizing greenhouse gas emissions. The integration of **motion detection sensors** optimizes energy usage by activating lights only when needed, significantly reducing **power wastage and light pollution**, thereby enhancing highway safety and efficiency.

Furthermore, the use of **Arduino-based automation** allows for **intelligent control, real-time monitoring, and efficient energy management**. The combination of **renewable energy sources and smart sensing technologies** makes this system not only cost-effective but also environmentally friendly.

Looking ahead, the project has immense potential for **further enhancements** through **IoT-based monitoring, AI-driven adaptive lighting, advanced energy storage solutions, and smart grid connectivity**. With continuous advancements, this hybrid system can contribute significantly to **smart city development, sustainable transportation, and global climate change mitigation efforts**.

In conclusion, this project demonstrates a **practical and forward-thinking approach** to highway lighting, **promoting renewable energy utilization, reducing environmental impact, and fostering energy-efficient urban development**.

8. REFERENCE:

[1] Dual-sources energy harvesting system. K. Gowri, S. Ragul, R. Santhosh, R. Selvam,R. Yuvaraj. 2024

[2] A Hybrid Power Generation System Utilizing Solar and Wind Energy on Highways. Udit Mitta 2022.

[3] Mochamad Choifin, Achmad Fathoni Rodli, Anita Kartika Sari, A Study Of Renewable Energy And Solar Panel Literature Through Bibliometric Positioning During Three Decades, DigitalCommons@University of Nebraska – Lincoln, July 2021

[4] J. Zheng, J. Du, B. Wang, J. J. Klemeš, Q. Liao, and Y. Liang, "A hybrid framework for forecasting power generation of multiple renewable energy sources," Renew. Sustain. Energy Rev., vol. 172, Feb. 2023, Art. no. 113046.

[5] A. M. Shaheen, A. M. Elsayed, A. R. Ginidi, E. E. Elattar, and R. A. El-Sehiemy, "Effective automation of distribution systems with joint integration of DGs/SVCs considering reconfiguration capability by jellyfish search algorithm," IEEE Access, vol. 9, pp. 92053–92069, 2021.

[6] M. A. Koondhar, I. A. Channa, S. Chandio, M. I. Jamali, A. S.

Channa, and I. A. Laghari, "Temperature and irradiance based analysis the specific variation of PV module," Jurnal Teknologi, vol. 83, no. 6, pp. 1–17, Sep. 2021..

[7] N. Das, H. Wongsodihardjo, and S. Islam, "Modeling of multi-junction photovoltaic cell using MATLAB/SIMULINK to improve the conversion efficiency," Renew. Energy, vol. 74, pp. 917–924, Feb. 2015.

[8] A. Abu-Siada and S. M. Islam, "Applications of power electronics in renewable energy systems," in Power Electronics Handbook. Amsterdam, The Netherlands: Elsevier, 2024, pp. 797–843.

[9] V. S. Nayagam, A. P. Jyothi, P. Abirami, J. Femila Roseline, M. Sudhakar, E. A. Al-Ammar, S. M. Wabaidur, N. Hoda, and A. Sisay, "Deep learning model on energy management in grid-connected solar systems," Int. J. Photoenergy, vol. 2022, pp. 1–8, May 2022

[10] J. D. Vergara-Dietrich, M. M. Morato, P. R. C. Mendes, A. A. Cani, J. E. Normey-Rico, and C. Bordons, "Advanced chance-constrained predictive control for the efficient energy management of renewable power systems," J. Process Control, vol. 74, pp. 120–132, Feb. 2019.

[11] D. Azuatalam, K. Paridari, Y. Ma, M. Förstl, A. C. Chapman, and G. Verbič, "Energy management of small-scale PV-battery systems: Asystematicreviewconsideringpracticalimplementation, computational requirements, quality of input data and battery degradation," Renew. Sustain. Energy Rev., vol. 112, pp. 555–570, Sep. 2019.

[12] M. Alhussein, S. I. Haider, and K. Aurangzeb, "Microgrid-level energy management approach based on short-term forecasting of wind speed and solar irradiance," Energies, vol. 12, no. 8, p. 1487, Apr. 2019.

[13] B. Benlahbib, N. Bouarroudj, S. Mekhilef, D. Abdeldjalil, T. Abdelkrim, F. Bouchafaa, and A. Lakhdari, "Experimental investigation of power management and control of a PV/wind/fuel cell/battery hybrid energy system microgrid," Int. J. Hydrogen Energy, vol. 45, no. 53, pp. 29110–29122, Oct. 2020.

[14] A. Colmenar-Santos, M. Monteagudo-Mencucci, E. Rosales-Asensio, M. de Simón-Martín, and C. Pérez-Molina, "Optimized design method for storage systems in photovoltaic plants with delivery limitation," Sol. Energy, vol. 180, pp. 468–488, Mar. 2019.

[15] R. Siddaiah and R. P. Saini, "A review on planning, configurations, modeling and optimization techniques of hybrid renewable energy systems for off

grid applications," Renew. Sustain. Energy Rev., vol. 58, pp. 376–396, May 2016.

[16] T. Ma and M. S. Javed, "Integrated sizing of hybrid PV-wind-battery system for remote island considering the saturation of each renewable energy resource," Energy Convers. Manage., vol. 182, pp. 178–190, Feb. 2019.

[17] O. Majeed Butt, M. Zulqarnain, and T. Majeed Butt, "Recent advancement in smart grid technology: Future prospects in the electrical power network," Ain Shams Eng. J., vol. 12, no. 1, pp. 687–695, Mar. 2021.

[18] Y. Zhang, Y. Yang, and L. Dai, "Energy efficiency maximization for device-to-device communication underlaying cellular networks on multiple bands," IEEE Access, vol. 4, pp. 7682–7691, 2016.

[19] M. Dashtdar, M. Bajaj, and S. M. S. Hosseinimoghadam, "Design of optimal energy management system in a residential microgrid based on smart control," Smart Sci., vol. 10, no. 1, pp. 25–39, Jan. 2022.

[20] J. Jurasz, F. A. Canales, A. Kies, M. Guezgouz, and A. Beluco, "A review on the complementarity of renewable energy sources: Concept, metrics, application and future research directions," Sol. Energy, vol. 195, pp. 703–724, Jan. 2020.

[21] S. Alatai, M. Salem, D. Ishak, H. S. Das, M. A. Nazari, A. Bughneda, and M. Kamarol, "A review on state-of-the-art power converters: Bidirectional, resonant, multilevel converters and their derivatives," Appl. Sci., vol. 11, no. 21, p. 10172, Oct. 2021

[22] S.SaravananandN.RameshBabu,"Analysisa ndimplementationofhigh step-up DC–DC converter for PV based grid application," Appl. Energy, vol. 190, pp. 64–72, Mar. 2017.

[23] E. Kabalci, Multilevel Inverters: Control Methods and Advanced Power Electronic Applications. New York, NY, USA: Academic, 2021.

[24] F. Mumtaz, N. Zaihar Yahaya, S. Tanzim Meraj, B. Singh, R. Kannan, and O. Ibrahim, "Review on non-isolated DC–DC converters and their control techniques for renewable energy applications," Ain Shams Eng. J., vol. 12, no. 4, pp. 3747–3763, Dec. 2021.

[25] A. Kolli, A. Gaillard, A. De Bernardinis, O. Bethoux, D. Hissel, and Z. Khatir, "A review on DC/DC converter architectures for power fuel cell applications," Energy Convers. Manage., vol. 105, pp. 716–730, Nov. 2015.

[26] M. J. Khan and L. Mathew, "Comparative study of maximum power point tracking techniques for hybrid renewable energy system," Int. J. Electron., vol. 106, no. 8, pp. 1216–1228, Aug. 2019.

[27] T. Arunkumari and V. Indragandhi, "An overview of high voltage conversion ratio DC–DC converter configurations used in DC micro-grid architectures," in Proc. Renew. Sustain. Energy Rev., vol. 77, Apr. 2017, pp. 670–687.

[28] P. E. Bett and H. E. Thornton, "The climatological relationships between wind and solar energy supply in Britain," Renew. Energy, vol. 87, pp. 96–110, Mar. 2016.

[29] S. Iqbal, M. U. Jan, Anis-Ur-Rehman, A. U. Rehman, A. Shafiq, H. U. Rehman, and M. Aurangzeb, "Feasibility study and deployment of solar photovoltaic system to enhance energy economics of King Abdullah campus, University of Azad Jammu and Kashmir Muzaffarabad, AJK Pakistan," IEEE Access, vol. 10, pp. 5440–5455, 2022.

[30] S. Younsi, O. Kahouli, N. Hamrouni, H. Alsaif, A. Aloui, and S. Hamed, "Performance analysis and multi-mode control of grid connected micro wind–solar hybrid generator in Saudi Arabia," J. Taibah Univ. Sci., vol. 16, no. 1, pp. 550–565, Dec. 2022.