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SMART HIGHWAY WITH GREEN ENERGY

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Abstract— **The growing demand for sustainable infrastructure and intelligent transportation systems has led to the development of smart highways powered by renewable energy. This paper proposes a Smart Highway System that integrates green energy sources with automated monitoring and control mechanisms to enhance safety, efficiency, and sustainability. The system employs solar panels and wind turbines with Maximum Power Point Tracking (MPPT) to ensure efficient energy harvesting and storage in a 12V battery. An ATmega8 microcontroller serves as the core controller, interfacing with sensors such as an LDR for streetlight automation, a soil moisture sensor for environmental monitoring, and manual switches for user inputs. The processed data is utilized to control various highway applications through a relay module, including intelligent street lighting, water pumping, electric vehicle (EV) charging, and emergency alert systems using GSM communication. Additionally, red LEDs and buzzers provide immediate warnings for hazardous conditions, thereby improving highway safety. The proposed system minimizes dependency on conventional grid electricity, reduces operational costs, and contributes to environmental sustainability by leveraging renewable resources. This model demonstrates an effective approach to integrating smart technology with green energy for next-generation highway infrastructure.**

Keywords— **Solar panel, wind turbine, GSM Module, street light, microcontroller, ldr sensor, relay.**

I. INTRODUCTION

Highways play a crucial role in connecting cities and supporting economic growth, but they also face several real-time challenges that affect safety, efficiency, and sustainability. Conventional street lighting systems on highways consume large amounts of grid electricity, leading to high operational costs and increased carbon emissions. In many remote or rural areas, the absence of reliable grid supply further limits the availability of continuous lighting and monitoring. Additionally, the lack of automated systems for detecting accidents, providing timely alerts, or monitoring environmental conditions often results in delayed responses, which can increase the severity of road mishaps. Waterlogging due to poor monitoring of soil and drainage conditions is another problem that disrupts traffic flow and endangers drivers.

At the same time, the rising number of electric vehicles (EVs) demands on-road charging facilities, but current highway infrastructure is not adequately equipped to support this requirement. These issues highlight the urgent need for a sustainable and intelligent system that can combine renewable energy utilization with automated monitoring and real-time decision-making.

The proposed Smart Highway with Green Energy addresses these challenges by integrating solar and wind-based renewable power generation with a microcontroller-driven monitoring and control system. Automated street lighting using LDR sensors reduces energy wastage, soil moisture sensing enables smart water management, and GSM-based alerts improve emergency response. Furthermore, the system supports EV charging and employs warning indicators like LEDs and buzzers to enhance road safety. By adopting this approach, highways can become more energy-efficient, eco-friendly, and safer for travelers.

II. PROPOSED ALGORITHM

The proposed Smart Highway with Green Energy system follows a step-by-step algorithm that integrates renewable energy harvesting with intelligent monitoring and control. Initially, power is generated through solar panels and wind turbines, optimized using a Maximum Power Point Tracking (MPPT) unit, and stored in a 12V battery to ensure uninterrupted operation. Once the system is initialized, the ATmega8 microcontroller continuously collects input data from sensors and switches. The Light Dependent Resistor

(LDR) sensor monitors ambient light levels to automate street lighting, while the soil moisture sensor evaluates ground conditions to control the water pump for irrigation or drainage purposes. Manual and emergency switches provide additional user inputs for safety and operational control. Based on these inputs, the microcontroller processes the data and executes decision-making operations. For example, during low-light conditions, the street lights are activated, whereas they remain off when sufficient light is detected. Similarly, if soil moisture levels fall below the threshold, the water pump is turned on. In the case of emergencies, the GSM module transmits alert messages, and safety indicators such as a red LED and buzzer are triggered to warn road users. Furthermore, the system supports electric vehicle (EV) charging by enabling the EV power supply on demand. All these actions are carried out through the relay module, which interfaces the microcontroller with high-power devices. The algorithm operates in a continuous loop, ensuring real-time monitoring, automated control, and efficient energy utilization, thereby making the highway infrastructure more sustainable and intelligent.

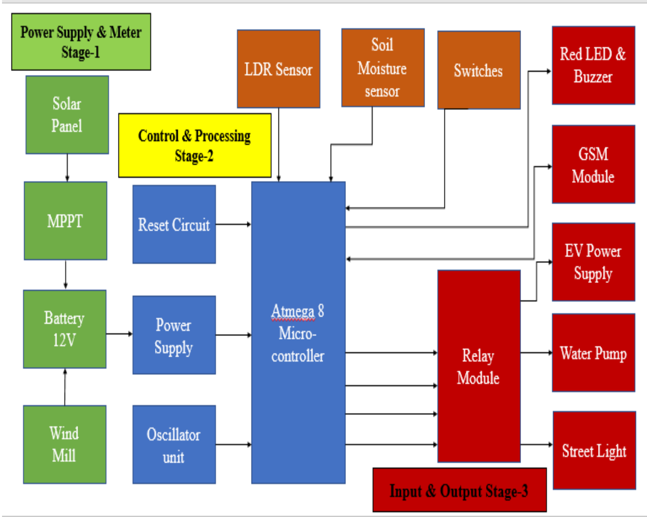

Fig.1 Block diagram

In the proposed system, a solar panel is installed near the battery storehouse to ensure efficient power generation and management. During the daytime, the solar panel captures solar radiation through the photovoltaic effect and converts it into electrical energy. This harvested energy is stored in the battery bank, which acts as a reserve to power the system during nighttime, adverse weather conditions, or emergencies. The stored energy is then utilized for operating streetlights and other highway applications. The control system plays a vital role in ensuring energy efficiency and reliability. An LDR (Light Dependent Resistor) sensor monitors ambient light intensity to regulate the streetlights. During daylight, the lamps remain OFF, while after sunset or in low-light conditions, the system automatically switches ON the lamps. To further optimize energy consumption, an IR sensor detects vehicle movement on the highway. When no movement is detected, the LED streetlights operate at a minimum brightness level (about 10%), thereby conserving energy. Once a vehicle is detected, the microcontroller (ATmega328) activates the upcoming streetlights at 100% brightness, while the previous ones return to minimum brightness. This intelligent switching mechanism significantly reduces unnecessary energy wastage and ensures that maximum illumination is provided only when required. Such an approach can be effectively implemented in highways, urban streets, public places, and high-traffic areas to promote electricity conservation and enhance road safety.

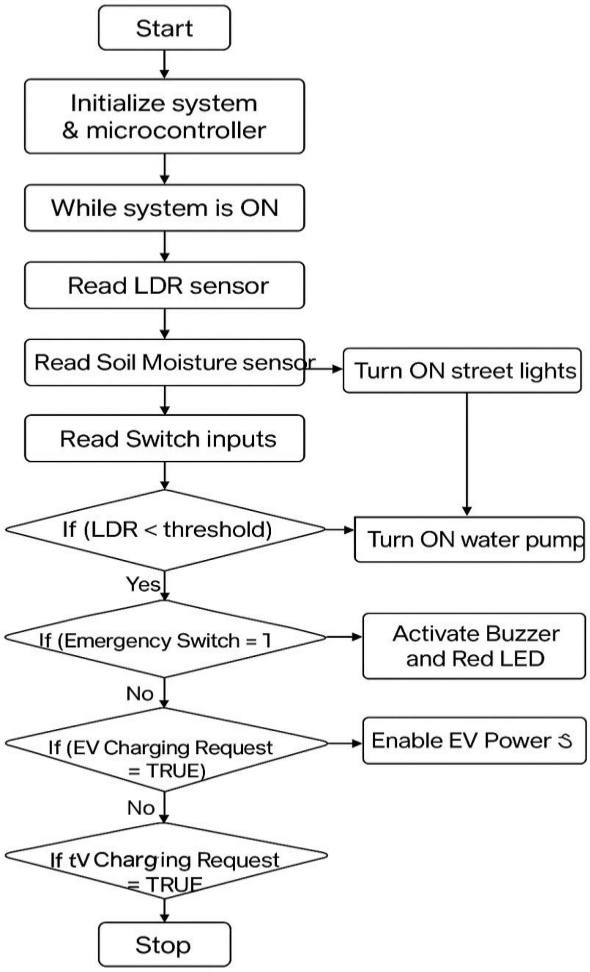

Fig.2 Flowchart

III. EXPERIMENT AND RESULT

To validate the proposed Smart Highway with Green Energy system, a prototype model was developed and tested under real-time conditions. The experimental setup consisted of a solar panel connected to an MPPT controller for maximum power extraction, with energy stored in a 12V battery bank. An ATmega328 microcontroller was used to control the system, interfaced with an LDR sensor, IR sensor, soil moisture sensor, relay module, and output devices such as LED lamps, buzzer, and GSM module. The streetlight units were implemented using energy-efficient LED lamps arranged along a miniature highway model.

During daytime testing, the solar panel successfully generated electricity from incident sunlight, which was stored in the battery bank for later use. The LDR sensor ensured that streetlights remained OFF during sufficient daylight. As evening approached, the LDR triggered automatic switching of lamps to ON state. Further testing of the IR sensor confirmed that vehicle movement was detected accurately; when no vehicle was present, the streetlights operated at 10% brightness, while detection of a vehicle increased the brightness of upcoming lamps to 100%. This dynamic control achieved significant energy savings compared to conventional continuous full-brightness lighting.

In adverse weather simulations and nighttime tests, the battery power supply provided uninterrupted operation, validating system reliability. The soil moisture sensor effectively controlled a miniature water pump, while the GSM module successfully transmitted alert messages during emergency switch activation. Quantitative results showed an approximate 40–50% reduction in energy consumption compared to a traditional highway lighting system. The integration of renewable energy with intelligent control not only ensured sustainable operation but also improved road safety through automated alerts and adaptive illumination.

Fig.3 Project Development

IV.CONCLUSION

The proposed Smart Highway with Green Energy successfully demonstrates the integration of renewable energy sources with intelligent control systems to create a sustainable and safe transportation infrastructure. By utilizing solar and wind power through an MPPT-controlled storage system, the model reduces dependence on conventional grid electricity and ensures uninterrupted operation during night and adverse weather conditions. Automated streetlight control using LDR and IR sensors effectively minimizes energy wastage by maintaining low illumination in the absence of vehicles and switching to full brightness only when movement is detected. Additional features such as soil moisture–based water pumping, GSM-based emergency alerts, and EV charging support further enhance the system's functionality and practical applicability.

Experimental results validate that the system can achieve significant energy savings while maintaining road safety and reliability. The combination of renewable energy harvesting and intelligent automation proves to be an efficient solution for addressing real-time highway challenges such as high electricity consumption, delayed emergency response, and insufficient infrastructure for electric vehicles.

In future work, the system can be scaled to larger highways with IoT-enabled monitoring, smart traffic management, and integration with cloud-based platforms for predictive maintenance and data analysis. Overall, the proposed model provides a cost-effective, eco-friendly, and intelligent approach to modernizing highway infrastructure.

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