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Design and Implementation of Automatic Solar Street Lighting Systems for Bangladesh

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Abstract— A solar-powered lighting system that works automatically has been designed and set up to meet the lighting needs of the people of Bangladesh. The designed system works well when there isn't much light because it uses photovoltaic panels, battery storage, and sensors to control it. LDR and motion sensors automatically change the brightness to save energy. The solution fixes the problem of power outages that happen too often, cuts down on maintenance costs, and encourages the use of renewable energy. The results show that the system works well in both urban and rural areas of Bangladesh, where it can be used by many people.

Keywords— Solar street lighting, Automatic control, LDR, Motion sensor, Energy efficiency, Bangladesh

I. INTRODUCTION

Bangladesh needs better streetlights that use less energy and work more reliably because the country is growing quickly, using more electricity, and having power outages often. Streetlights that run on the grid are more expensive and bad for the environment because they need to be fixed more often and put more strain on the country's power supply. Solar-powered automatic street lighting systems are a good option because they use a lot of sunlight, which makes them less dependent on the grid and safer at night in both cities and rural areas. These systems can work automatically and well because they have photovoltaic panels, rechargeable batteries, LED lights, and automatic sensing devices. They use less energy all night and only turn on when they need to. This kind of technology is suitable for Bangladesh's changing energy needs because it lowers costs, improves public infrastructure, and helps the country reach its renewable energy goals.

II. THEORY AND METHODOLOGY

The principles of photovoltaic energy conversion, energy storage, and sensor-based control make automatic solar street lighting systems work. These systems provide a cheap and independent way to light up the streets. The main parts of the system include solar panels, batteries, LED lights, charge controllers, and sensors like optional PIR (Passive Infrared) motion sensors and LDRs (Light Dependent Resistors). Solar panels turn sunlight into electricity, and a charge controller makes sure that the battery doesn't get too full or too empty. This makes sure that the battery will last a long time and that there will always be power available at night. LEDs are used as the light source because they last a long time, use little power, and work very well. The LDR lets the system switch between day and night modes without any problems by constantly measuring the amount of light in the room. The controller turns on the LEDs when it sees darkness. Optional PIR motion sensors make things more efficient and save energy when the street is empty by only turning up the brightness when movement is detected.

$$P_{PV}=V_{PV}\times I_{PV} \ldots\ldots(1)$$

Equation (1) shows how much electricity the solar panel makes based on its output voltage and current. It helps describe how much power is likely to be available during the day for charging the battery. This is important to figure out the energy balance of the machine.

These parts work together to make the system work. During the day, solar energy is collected and stored, and at night, it is released to power the LEDs. The PIR sensor changes the brightness of the lights based on whether a person or car is nearby, and the LDR makes sure that the lights don't come on until after dark. This makes the system more flexible, which saves energy and extends battery life.

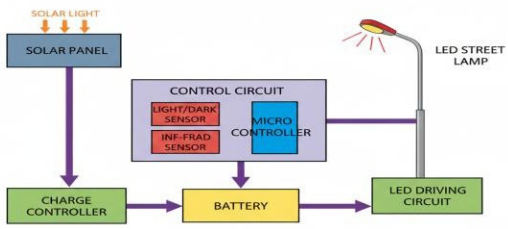

Figure-1: Solar Street Light Control System Diagram

The above diagram shows how a system of automatic solar street lights works. The Charge Controller sends the sunlight that the Solar Panel collects to the Battery, where it is stored. The Control Circuit is the most important part of the system.

There is a microcontroller, a light/dark sensor, and an infrared sensor in it. The Microcontroller can tell how bright it is outside thanks to the Light/Dark Sensor. The light comes on by itself when it gets dark and goes off when it gets light. The Infra-Red Sensor probably adds a way to see movement, which lets the system save energy by dimming the light and only brightening it when it sees a person or car. The Microcontroller finally turns on the LED Street Lamp with an LED Driving Circuit.

III. Literature Review

Hybrid renewable energy systems have been extensively studied to enhance power reliability in urban and rural applications. Yang et al. [1] demonstrated the significance of meteorological data in optimizing the probabilistic performance of hybrid photovoltaic (PV)–wind systems. Ismail et al. [2] proposed a PV–microturbine hybrid system for small-scale remote applications, emphasizing efficient scaling. Rehman and Al-Hadhrami [3] looked into a solar PV–diesel–battery hybrid system and found that it could be a cheap way for people who live off the grid to get power. Chauhan and Saini [4] found important design problems and ways to combine different generations of renewable systems when they looked at them.

For solar street lighting, Kumar and Solanki [6] used IoT to monitor and control the lights, which made them more efficient. Bhattacharjee and Acharya [5] made and put into place an automated solar street light control system. Focusing on saving energy, Mohammed et al. [8] made an automated solar-powered LED street light system that works well in the area. Abdollahi et al. [9] focused on minimizing lighting and adaptive control in their study of smart and energy-efficient street lighting systems. Ustun et al. [10] gave information about microgrid improvements which are important for decentralized lighting systems.

Faruk et al. [11] evaluated autonomous solar street lighting systems in Bangladesh, delivering performance metrics within specific regional environmental contexts. Das et al. [12] created a smart solar street lighting design for developing countries that uses sensors and adaptive controllers to cut down on energy use and maintenance needs. These scenarios provide a basis for developing reliable and contextually suitable solar street lighting systems.

IV. Circuit Design and Performance Analysis

The block diagram shows how an Automatic Solar Street Lighting System changes and moves energy in a systematic way. The solar panel is the first step in this process.

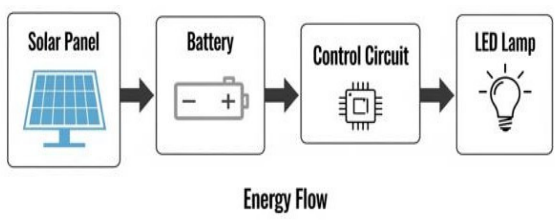

Figure-2: Block Diagram

It is the main way to get energy. It changes sunlight directly into DC electrical power using the photovoltaic effect.

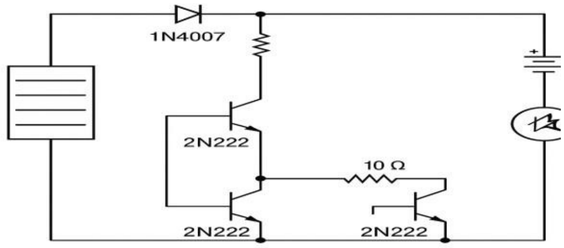

Fig-3: Circuit diagram

The circuit diagram that comes with it shows a simple automatic switching system for a solar street light that works with transistors. The solar panel works as both a light sensor and a power source. It uses the 1N4007 blocking diode to charge the 3.7V battery.

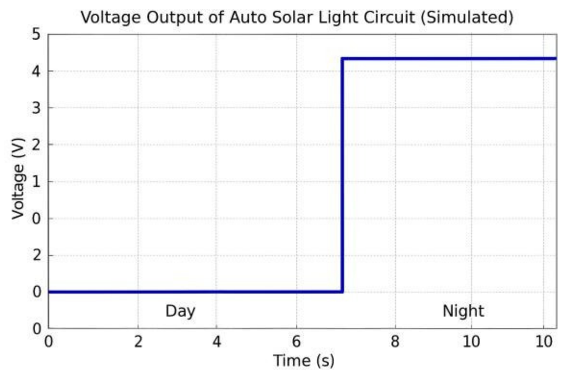

Figure-4: Voltage output(From Simulink)

The voltage difference between the resistors keeps the first 2N2222 NPN transistor ON (saturated) all day (high solar panel voltage). This keeps the second switching transistor OFF and the LED lamp OFF.

$$\text{SOC}=\frac{\textit{Energy stored}}{\textit{Energy of battery capacity}}\times 100\%\ldots (2)$$

Equation (2) shows how much power is in the battery at the moment. This helps explain how the machine keeps enough energy for overnight use. It helps people talk about how well the battery will work over time.

As the sun goes down, the first transistor's base current drops, which turns it off. This change lets the battery voltage turn on the second transistor (usually to saturation), that closes the circuit and turns on the LED lamp. The MATLAB simulation output ensures this behavior by showing a low-voltage output (about 0V) during the simulated "Day" period and a sharp change to a high-voltage output (about 4.4V) during the simulated "Night" period (after 7s). This confirms that the light-driving stage was successfully turned on automatically.

V. SYSTEM PERFORMANCE AND ENERGY EFFICIENCY

In Bangladesh, the performance of autonomous solar street lighting systems is affected by changes in the weather throughout the year, the differences between urban and rural deployment conditions, and the amount of sunlight that hits the ground. Field studies show that well-designed systems with high-efficiency photovoltaic panels and LED lighting can function reliably for 10 to 12 hours every night, even during the monsoon season when there isn't much sunlight. By ensuring that energy is only used when needed, the combination of motion and light sensors cuts down on battery drain and makes the system last longer.

$$P_{LED}=V_{LED}\times I_{LED} \text{ ....(3)}$$

Equation (3) delineates the power necessary to operate the LED bulb. It effectively demonstrates how low-power LEDs enhance overall system efficiency. It is also associated with battery discharge estimation.

Using LEDs, which use a lot less power than regular sodium-vapor or fluorescent lights but still give off a lot of light, is another way to save energy. In cities with a lot of street lighting, automated dimming and adaptive control can cut energy use by 30% to 40% without putting safety at risk. Automatic solar street lights are a reliable off-grid option that cuts down on the need for expensive diesel generators and unreliable grid electricity in rural areas. In the end, these systems are a very nice choice for Bangladesh because they save cities money on energy and help the environment by cutting down on carbon emissions.

$$V_{out}=Vi_n\left(\frac{R_{LD}R}{R_{LDR}+R_{fixed}}\right) \text{ ....(4)}$$

Equation (4) elucidates how the LDR detects variations in daylight by generating a fluctuating voltage. It directly facilitates the automatic transition between day and night. It correlates with the elucidation of transistor behavior derived from the circuit diagram.

$$E = \frac{I}{d^2} \text{....... (5)}$$

Equation (5) illustrates the decline in illuminance on the ground as the distance from the LED light source rises. This connection ascertains if a solar street light, positioned at a particular pole height, can provide enough illumination for roads or pathways. By comprehending the propagation of illumination, designers can enhance mounting height and LED intensity to guarantee uniform lighting efficacy in both urban and rural settings.

The relationship between LED power usage and load helps figure out how much power the lighting unit needs from the battery at night, which has a direct effect on how well the system works and how long the backup lasts. The LDR voltage-divider behavior explains how changes in the light level in the room send a control signal that makes the lamp turn on and off automatically, ensuring that it always works. The illumination relationship based on distance explains why the ground gets less bright as the pole gets taller. This helps choose the right mounting heights and LED levels for even and good street lighting coverage.

VI. OPERATIONAL AND ENVIRONMENTAL LIMITATIONS

In Bangladesh, automatic solar street lights don't work as well as they should because they don't always get the same amount of sunlight. This is specially very true in the monsoon season, when clouds block a lot of the sun. Dust on solar panels makes them work less well, and it's not an easy task to keep them clean in remote or rural areas. Batteries lose their ability to store energy over time, which means that lights don't last as long on long nights. The panels don't get enough sunlight in a lot of places because they are put up at the wrong angle or they are blocked by trees or big buildings nearby. Extreme weather, like high humidity, heavy rain, and storms, can damage electronic parts and minimize the life span of systems. Also, in some places, there aren't enough people who know how to fix things, which makes it harder to do so quickly and makes operations less reliable over time.

VII. CONCLUSION AND FUTURE SCOPES

Bangladesh's use of automatic solar street lights is a nice example of how to solve energy problems in both cities and the countryside in a way that is both useful and long-lasting. The study says that solar-powered LED street lights with sensors and energy storage devices can greatly reduce the need for traditional grid electricity while still providing reliable light at night. The system works on its own by detecting ambient light, which saves energy and extends battery life. This makes it a cost-effective choice for communities and governments. The design is also scalable and modular, which means it can be used in many different environmental and socioeconomic situations in Bangladesh.

There are many opportunities to make things better in the future. In the future, smart monitoring systems for predictive maintenance and real-time performance tracking could be added, making the whole system more reliable. Using the latest energy storage technologies, like hybrid or lithium-ion battery systems, can make things even more efficient and require less maintenance. Adding Internet of Things (IoT) connections and renewable energy hybridization, which combines solar with small-scale wind or kinetic energy, can also make street lighting networks more flexible and durable. If many people in Bangladesh used these kinds of inventions, it could have a big positive effect on saving energy, protecting the environment, and growing cities in a way that lasts.

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