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SolarSwift: Quick and Clean USB Charging Multinode Station for Public

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Abstract - The SolarSwift project proposes a stand-alone, solar-powered USB charging multinode station intended for public use in areas such as bus stops, railway stations, college campuses, marketplaces, and rural locations. In recent years, mobile phones have become essential for communication, digital transactions, navigation, and emergency services. However, the availability of convenient and reliable charging facilities remains limited, particularly in regions affected by irregular grid power supply. To overcome this limitation, the SolarSwift system utilizes a 12 V photovoltaic panel combined with a charge controller, a rechargeable battery, and a high-efficiency DC–DC buck converter to provide a stable and regulated 5 V output suitable for multiple USB charging ports. In addition to device charging, the system integrates an automatic LED streetlight controlled using a light-dependent resistor (LDR), allowing illumination during nighttime conditions without reliance on external electricity. The design approach emphasizes efficient energy management, compact structure, voltage stability, and battery protection to ensure reliable operation under varying environmental conditions. Performance evaluation through practical observations and simulation indicates consistent charging performance, sufficient energy storage, and dependable operation throughout day and night cycles. The SolarSwift system highlights the potential of decentralized solar solutions to improve public convenience, reduce dependence on conventional power sources, and promote sustainable and inclusive energy infrastructure in both urban and rural settings.

Keywords: solar-powered charging, renewable energy, USB charging station, buck converter, automatic streetlight, public infrastructure.

1.INTRODUCTION

In recent years, mobile phones and portable electronic devices have become an essential part of everyday life. These devices support communication, navigation, online learning, digital payments, and emergency services, making continuous access to power increasingly important. As digital dependence grows, the need for easily accessible charging facilities in public locations has also increased. However, many public spaces—especially in rural, semi-urban, and developing regions—still lack reliable and convenient charging infrastructure. Existing grid-based charging solutions often suffer from frequent power interruptions, high installation costs, and ongoing maintenance requirements, limiting their effectiveness in such environments.

Renewable energy, particularly solar power, offers a practical alternative to overcome these challenges. Solar energy is clean, sustainable, and widely available across most regions of India, making it suitable for decentralized public utility systems. Solar-based installations can operate independently of the electrical grid, reducing dependency on conventional power sources while also minimizing environmental impact. The integration of solar technology into public infrastructure provides a cost-effective and long-term solution for addressing energy accessibility issues.

Motivated by these considerations, the SolarSwift project is designed as a stand-alone solar-powered USB charging multinode station integrated with an automatic LED streetlight. The system utilizes a photovoltaic (PV) panel to harvest solar energy, which is regulated through a charge controller and stored in a rechargeable battery. A DC–DC buck converter is used to provide a stable 5 V output required for safe and efficient charging of multiple electronic devices simultaneously. To improve usability during nighttime hours, an LED streetlight controlled by a light-dependent resistor (LDR) is incorporated, enabling automatic operation based on ambient lighting conditions.

This work aims to demonstrate the feasibility of combining public charging and lighting services into a single solar-powered system that is compact, reliable, and independent of the power grid. By adopting renewable energy-based infrastructure, such systems can enhance digital accessibility, improve public convenience, and contribute to sustainable development. The following Literature Review discusses existing solar charging solutions, highlights their limitations, and establishes the relevance of the proposed SolarSwift system within modern public utility applications.

2. LITERATURE REVIEW

The increasing reliance on mobile phones and digital services has led to a growing demand for accessible and reliable charging facilities in public spaces. Conventional grid-powered charging solutions often face limitations such as frequent power outages, high installation costs, and maintenance challenges, particularly in rural and semi-urban regions. As a result, researchers have increasingly explored solar-powered charging systems as a sustainable and grid-independent alternative. Existing studies in this domain range from small portable charging devices to large stationary public charging stations.

Initial research efforts primarily focused on portable solar charging solutions intended for individual or emergency use. Rahaman et al. proposed a hybrid mobile charging system that combined a photovoltaic panel with a hand-crank generator to ensure charging capability during low-light or nighttime conditions. Similarly, Vijay et al. developed a wind–solar hybrid charger to improve power availability under varying environmental conditions. While these designs demonstrated innovation in renewable energy utilization, their low power output and limited scalability make them unsuitable for multi-user public applications.

Further studies examined compact solar-powered USB charging units designed for basic mobile charging. Mudi presented a portable 5 V solar charger capable of charging standard mobile devices efficiently. Wearable solar solutions such as solar caps and backpacks were also investigated, integrating small photovoltaic modules into everyday accessories. Although these approaches improved portability, they lacked sufficient power capacity, durability, and structural suitability for continuous public use.

A significant body of work has focused on stationary solar charging stations intended for public installation. Chowdhury et al. introduced a solar-powered portable charging unit with battery backup for disaster-prone areas, ensuring electricity availability during grid failures. Udayalakshmi and Sheik proposed a solar-based public charging station with voltage regulation to support smartphones and feature phones. Other researchers explored coin-operated charging systems and solar-tracking mechanisms to enhance energy harvesting efficiency. Despite their effectiveness, many of these systems supported only a limited number of charging ports and did not include additional public utilities such as lighting.

Recent developments include large solar canopy charging stations designed for high-capacity public use. These systems integrate sizable photovoltaic arrays, deep-cycle batteries, and multiple AC/DC charging interfaces capable of powering laptops and mobile devices. While such installations offer high energy autonomy and charging capacity, they require considerable space, higher investment, and regular maintenance, which restricts their deployment in smaller public locations or rural communities.

A critical analysis of existing literature highlights several gaps. Many solar-powered charging systems provide limited USB ports, reducing usability in high-traffic public areas. Most designs focus solely on charging functionality and do not integrate automatic street lighting, which is essential for nighttime safety and accessibility. Additionally, systems with insufficient energy storage remain dependent on sunlight availability, while large-scale installations are often impractical due to cost and space constraints.

To overcome these limitations, the proposed SolarSwift system combines a compact multiport USB charging station with an LDR-controlled LED streetlight powered entirely by solar energy. This integrated approach addresses both charging accessibility and public illumination within a single, low-cost, and grid-independent system. The SolarSwift design therefore represents an effective and practical enhancement over existing solutions, particularly for small public spaces requiring reliable daytime and nighttime operation.

3. SYSTEM DESIGN AND METHODOLOGY

This section describes the overall system architecture, design approach, and working methodology of the SolarSwift system. The aim is to explain how the solar-powered USB charging multinode station and the automatic LED streetlight operate together as a single, self-contained public utility. Each subsection focuses on a specific component or functional process to provide a clear and systematic technical understanding of the proposed system.

3.1 System Overview

The SolarSwift system is a fully stand-alone, solar-powered configuration designed to provide regulated 5 V USB charging through multiple output ports while simultaneously supporting an automatic LED streetlight for nighttime illumination. The system operates independently of the electrical grid and integrates a solar photovoltaic (PV) panel, charge controller, rechargeable battery, DC–DC buck converter, and an LDR-based lighting control unit.

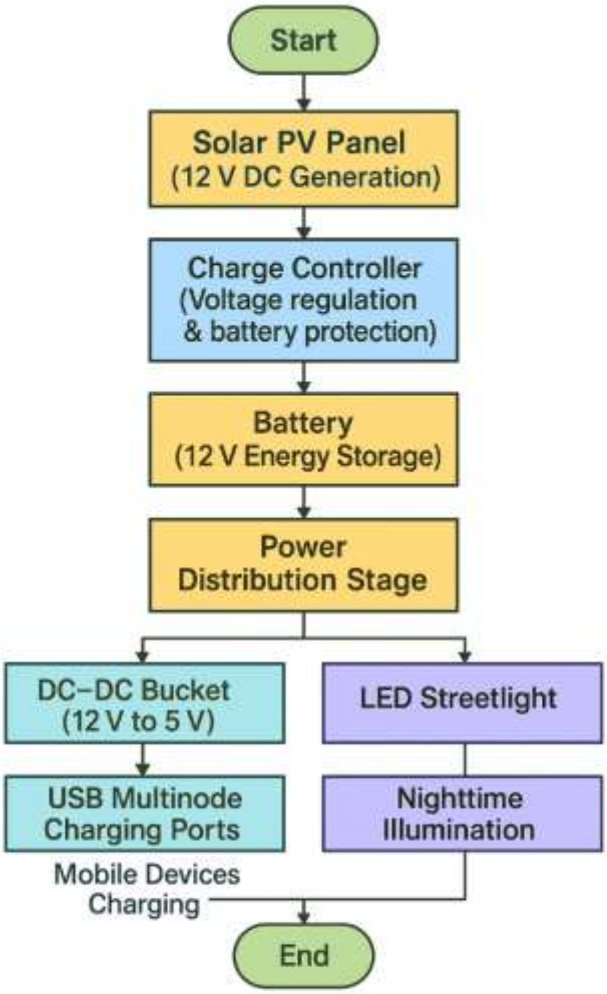

Fig. 1. Flowchart of the proposed SolarSwift system

3.2 Photovoltaic Energy Harvesting

A 12 V solar photovoltaic panel acts as the primary energy source for the system. During daylight hours, the panel converts incident solar radiation into direct current (DC) electrical power through the photovoltaic effect. The output depends on environmental conditions such as solar irradiance, temperature, panel orientation, and shading. The panel rating is selected to ensure sufficient power for simultaneous USB charging and effective battery charging for nighttime operation.

3.3 Charge Controller

The charge controller regulates the power transfer between the solar panel and the battery. It protects the battery from overcharging during peak sunlight conditions and prevents deep discharge during extended usage. By maintaining safe voltage and current levels, the controller improves overall system efficiency and extends battery life while ensuring reliable power delivery to connected loads.

3.4 Energy Storage System

A 12 V rechargeable battery serves as the system's energy storage unit. Excess energy generated during daytime is stored in the battery and later used to power the USB charging ports and LED streetlight during evening and nighttime hours. Battery capacity is selected based on expected charging demand, illumination duration, and backup requirements to ensure uninterrupted operation under varying weather conditions.

3.5 DC–DC Buck Converter

The DC–DC buck converter reduces the battery voltage from 12 V to a regulated 5 V required for USB charging. The converter ensures stable output despite variations in battery voltage caused by load changes or discharge. Its high efficiency minimizes power loss, reduces heat generation, and supports safe charging of multiple devices simultaneously.

3.6 USB Multinode Charging Station

The charging module consists of multiple USB ports designed to deliver regulated 5 V output in compliance with standard USB specifications. This multinode arrangement enables simultaneous charging of smartphones, power banks, Bluetooth devices, and other low-power electronics. Built-in overcurrent and short-circuit protection enhances system safety and reliability, making it suitable for public environments with frequent usage.

3.7 LED Streetlight Unit

An LED streetlight integrated with a light-dependent resistor (LDR) provides automatic illumination during low-light conditions. The LDR detects ambient light intensity and switches the streetlight ON at dusk and OFF at dawn without manual intervention. This automation ensures efficient use of stored solar energy and improves safety and visibility in public spaces during nighttime.

3.8 System Operation

During daytime operation, the solar PV panel supplies power to the USB charging ports and charges the battery through the charge controller. Excess energy is stored for later use. When ambient light levels decrease in the evening, the LDR activates the LED streetlight, which operates using stored battery energy. USB charging remains available throughout the night, ensuring continuous service without reliance on the electrical grid.

3.9 Advantages of the Proposed System

The SolarSwift system offers several advantages:

- Complete independence from conventional grid power
- Multiport USB charging suitable for public use
- Automatic and energy-efficient streetlight operation
- Low maintenance with long operational life
- Environmentally friendly and cost-effective design
- Suitable for deployment in both urban and rural locations

4. CONCLUSIONS

The SolarSwift system provides an effective, reliable, and sustainable solution for public mobile charging and nighttime illumination using renewable energy. By integrating a solar photovoltaic panel, charge controller, energy storage unit, DC–DC buck converter, and an LDR-controlled LED streetlight, the system operates independently of the electrical grid and offers continuous service throughout the day and night. The review of existing literature shows that while many earlier systems focused on either charging or lighting, SolarSwift combines both utilities into a single, user-friendly, and cost-efficient design.

The proposed system demonstrates that small-scale solar installations can significantly improve accessibility to essential digital services, especially in public, rural, and semi-urban environments where charging facilities are limited. Its multiport USB configuration, automatic streetlight operation, and low maintenance requirements make it suitable for widespread deployment. The study concludes that SolarSwift represents a practical step toward expanding renewable-energy-based public infrastructure and can be further enhanced in the future through improved power management, larger battery capacity, or smart monitoring features.

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