Eldi-Naseni Journal of Digital Innovation And Contemporary Research In Science, Engineering and Technology (ENJDICRSET) ISSN: 3093-0626 VOL.1 ISSUE 1, December, 2025. available online at www.eldi.org.ng/publication/VOL1_ISSUE1

DESIGN AND DEVELOPMENT OF A 50-USB-SLOT MINI SOLAR POWER STATION FOR RECHARGEABLE MOBILE DEVICES

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Abstract:

This project presents the design and development of a 50-USB-slot mini solar power station for rechargeable mobile devices with AC out source. The system harnesses solar energy using the PV modules, stores the harvested energy in a Battery Energy Storage System (BESS). A bulk dc to dc circuitry converts the energy stored in the BESS to regulated 5V, 3A DC voltage made available to the 50 USB slots for charging up to 50 devices simultaneously, also a DC to AC inverter system designed provides the 220V ac output for the charging of laptops and other devices that may require AC for operations. The station integrates a solar array, charge controller, a DC to AC inverter, an AC to DC converter, a lithium battery bank, and USB charging circuits, ensuring efficient energy management and robust protection against overload, short-circuits, and thermal issues. Designed for public spaces like campuses, markets, and transport hubs, the system offers a sustainable, off-grid charging solution. It promotes renewable energy adoption, reduces fossil fuel dependency, and addresses charging infrastructure gaps in areas with unreliable electricity. The station's compact, durable design ensures easy deployment and maintenance, making it an ideal solution for recharging mobile devices sustainably, ranging from mobile phones, tablets, laptops.

Key Words: Mini Solar Power, Rechargeable batteries, Mobile devices, charge controller, solar array, off-grid

I. Introduction

The increasing demand for mobile communication and electronics devices has led to a rise in power supply challenges. Despite lithium batteries, consistent access to power remains a challenge, especially in regions with inadequate electricity supply. The use of alternative charging systems that are sustainable, independent, and capable of serving multiple users is imperative. Solar-powered charging systems offer a promising solution, providing a renewable, clean, and sustainable source of energy.

The design and development of a 50-USB-slot mini solar charging station addresses these concerns by providing a centralized, publicly deployable, and locally maintainable system. This solution is particularly relevant for high-traffic settings such as campuses, transport terminals, marketplaces, and community ICT hubs. The project integrates a solar energy trapping unit,6 power conditioning circuitry, energy storage modules, regulated USB-based output channels, and an intelligent charging management subsystem.

The difficulties faced by many people in finding reliable charging options for their rechargeable mobile devices, particularly in regions with inadequate electricity supply. Conventional charging methods rely on electricity from the power grid, which may not be accessible during outages or in remote areas. In this project, a 50-USB-slot mini solar power station was design and develop capable of simultaneously charging multiple rechargeable mobile devices using solar energy as the primary power source.

The specific objectives include designing a solar power system, integrating an energy storage system, developing a stable 5V regulated USB power distribution architecture, incorporating electronic protection mechanisms, and constructing a robust physical enclosure. The project demonstrates the practical application of solar energy systems, power electronics, and distributed charging management, promoting clean energy usage and reducing dependency on fossil-fuel-driven power sources.

II. Review of Related Literatures

Solar energy is universally acknowledged as a major renewable resource, increasingly utilized globally for its sustainability, abundance, and significantly lower environmental impact compared to fossil fuels. Photovoltaic (PV) systems convert sunlight directly into electrical energy through semiconductor-based solar cell (Kalogirou, 2023). Improvements in manufacturing and lower costs per watt have made solar energy a practical option for decentralized power systems. Growing environmental concerns and the demand for dependable off-grid electricity, particularly in areas with weak or inadequate grid networks, have driven widespread interest in solar technologies (Ellabban et al., 2014). Small-scale solar applications such as mobile device charging provide energy accessibility in both urban and rural communities. According to Chandel et al. (2015), PV systems are economically suitable for distributed micro-power solutions, especially in public access infrastructures and low-power consumer electronics.

USB Charging Standards and Power Delivery

At first, the Universal Serial Bus (USB) standard was originally developed as a communication interface, but it has now become the foremost means for powering mobile electronic devices. USB 2.0 provides 5V at up to 500mA, while newer USB Battery Charging specifications allow currents up to 1.5A or more per port (USB-IF, 2010). Further developments in USB-C and USB Power Delivery (USB-PD) allow dynamic negotiation for higher power levels (up to 100W), although small handheld devices generally draw 5V at 1–2W (Rahman & Farooq, 2017). Equal power distribution, thermal management and stable voltage regulation remain critical in multi-port charging systems. Device charging efficiency degrades when voltage drops below 4.75V or when current supply is unevenly distributed (Li & Baruah, 2021) This technical constraint is central to designing a robust 50-slot charging hub. Many commercial USB hubs fail under simultaneous parallel loading due to insufficient regulation or inadequate heat dissipation. In multi-port applications, voltage drop due to cable resistance can cause slow charging or device malfunction, emphasizing the need for properly regulated distribution systems (Lee & Zhu, 2020). Therefore, the design objective for a 50-slot station requires robust current-handling capability and stable DC regulation.

Multi-Port Public Charging Infrastructure

Public charging frameworks can be categorized as grid-dependent, hybrid, or fully solar-powered systems. In grid-dependent charging installations face reliability and availability problems in environments with frequent power outages highlighting the advantage of solar-based independence (Khan & Quaicoe, 2013). Hybrid solutions integrate batteries and PV panels with the grid but result in higher installation cost (Raza et al., 2019). Deployment of solar charging kiosks provides affordable and sustainable charging options and demonstrates how renewable energy can bridge infrastructural gaps (Sovacool, 2017). Field studies from East Africa and South Asia demonstrate that solar charging stations significantly improve communication accessibility in rural populations where mobile phones are ubiquitous but home electrification is limited (Ondiek & Wafula, 2020).

Battery Storage in Solar Systems

Efficient energy storage is necessary for continuous operation of solar installations under fluctuations of sunlight availability. Lead-acid batteries are cost-effective but offer lower energy density and shorter cycle life relative to lithium-based systems (Buchmann, 2016). Comparative research demonstrates that LiFePO4 batteries can retain over 80% of capacity after 2000 cycles, whereas lead-acid batteries start declining noticeably after 300-500 cycles (Zhang et al., 2018).

Solar Charge Controllers and MPPT Optimization

Charge controllers manage power flow between PV panels and the battery. Pulse Width Modulation (PWM) controllers are cost-effective but operate below the PV panel's maximum power point (Hohm & Ropp, 2003). MPPT controllers dynamically track the PV optimum voltage/current combination, increasing harvested energy by up to 30% (Esram & Chapman, 2007).

Given seasonal shading variability and atmospheric transparency differences, MPPT systems are more effective in real-world outdoor deployments (Patel & Agarwal, 2008). For a high-density 50-device station, an MPPT-based controller would therefore be more desirable.

Power Distribution in Multi-Port USB Charging Systems

Large-scale USB charging hubs face challenges related to:

i. Thermal rise during high current draw
ii. Voltage drops across long distribution lines
iii. Unequal current delivery between ports
iv. Overload and short-circuit risk

Bus-bar based power distribution with individual fusing or converter modules for port clusters improves stability and reduces failure risk (Tembo & Zhou, 2021). Additionally, real-world testing confirms that distributed DC regulation yields better performance than a single-stage regulator powering many USB ports (Lee & Zhu, 2020).

Research Gaps

While previous studies have covered solar PV basics, USB standards, battery storage, and MPPT design, they have not sufficiently addressed high-density charging systems, real-time load balancing for large device clusters, or durability under heavy public use. This project bridges those gaps by introducing a solar-powered 50-slot charging station built for simultaneous multi-device operation in public and institutional settings.

III. Methodology

This covers the design requirements and specifications, the high-level description of the system, the system architecture and component selection based on specifications. Figure 1, shows the high-level description of the s... n. Generally, according to the specificati... vided by most smart phone stake holders l... Samsung e.t.c, the charging requir... verage smartphone is as shown bel...

- Voltage ... d USB voltage)
- Current: ... dep... on the device and ... ility)
- Power: 5W ... W (... for standard char...
- Connector: USB ... or Lightning ... ing ...

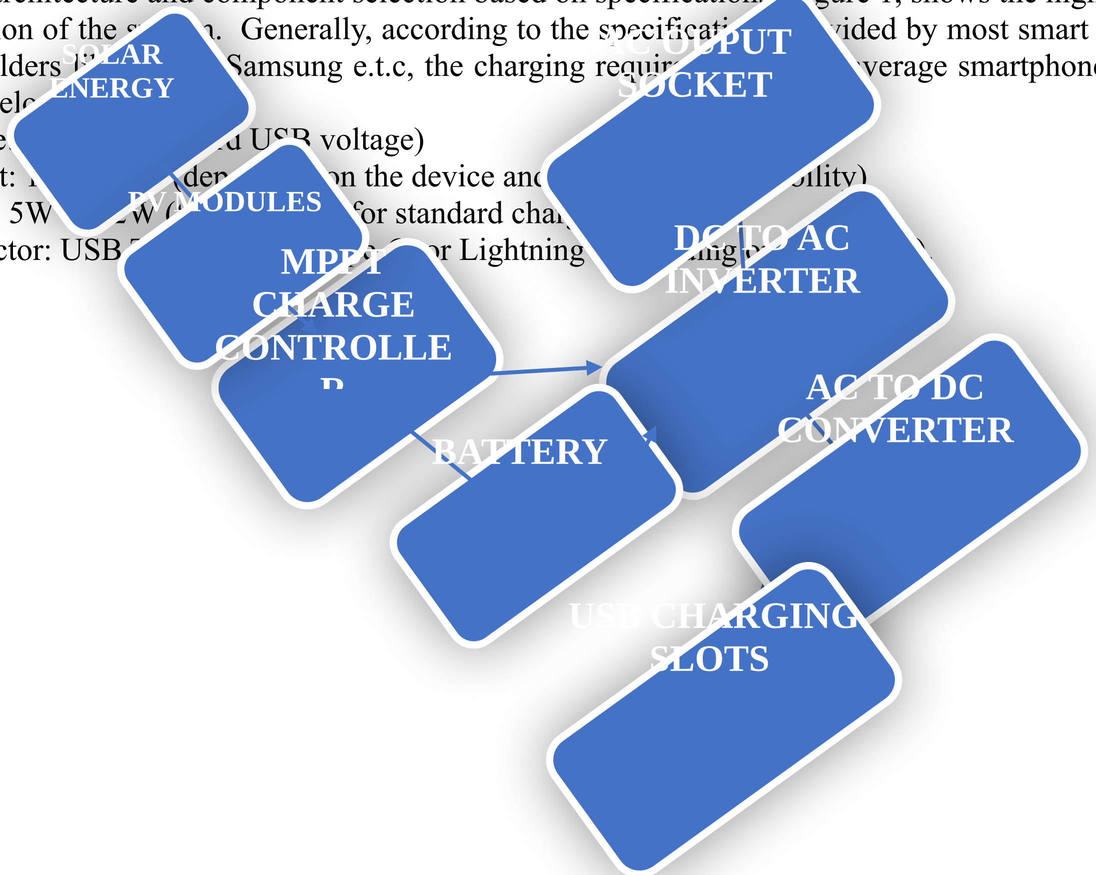

Figure 1: High level Description of the System

IV. Design Specifications

Therefore, the minimum power requirement for 50 USB slot will be 50x12W = 600W, with a minimum of 2.4A for each USB slot. Therefore, the design specification for this design was chosen with additional allowance to ensure that all variant of smart phone will be properly recharged. The design specification is as shown below;

For each USB slot
- Voltage: 5V DC (standard USB voltage)
- Current: 3A (for each USB slot)
- Power: 15W (deliverable from each USB slot)

For the Solar Charging
- Voltage: 5V DC (standard USB voltage)
- Current: 150A (for 50 USB slot)
- Power output: 750W (deliverable from 50 USB slot)
- Number of charging USB slots: 50
- Solar panel size: 2pcs of 550W, 55V =1,100W
- Battery capacity: 100AH, 13.2V
- Battery type: Lithium ion
- Solar Charge controller: 30A ,12V MPPT

V. System Design and Implementation

The solar panel array is arranged in series giving us a total 110V, 1100W, the output of the solar panel array is connected to the MPPT solar charge controller's PV terminal. The battery used is a Lithium ion, 100AH, 13.2V. The battery serves as a backup power supply for the system. During the day, when solar energy is available and sufficient, the power to recharge the mobiles devices comes from the solar panel through the MPPT charge controller directly. The excess energy from the solar panels is used to recharge the Lithium-ion battery. The backup is engaged to cushion variable and unstable weather conditions and during the night when solar energy is not available. Figure 2 show the block diagram of the system design. While Figure3 sh[illegible] the completed and package system.

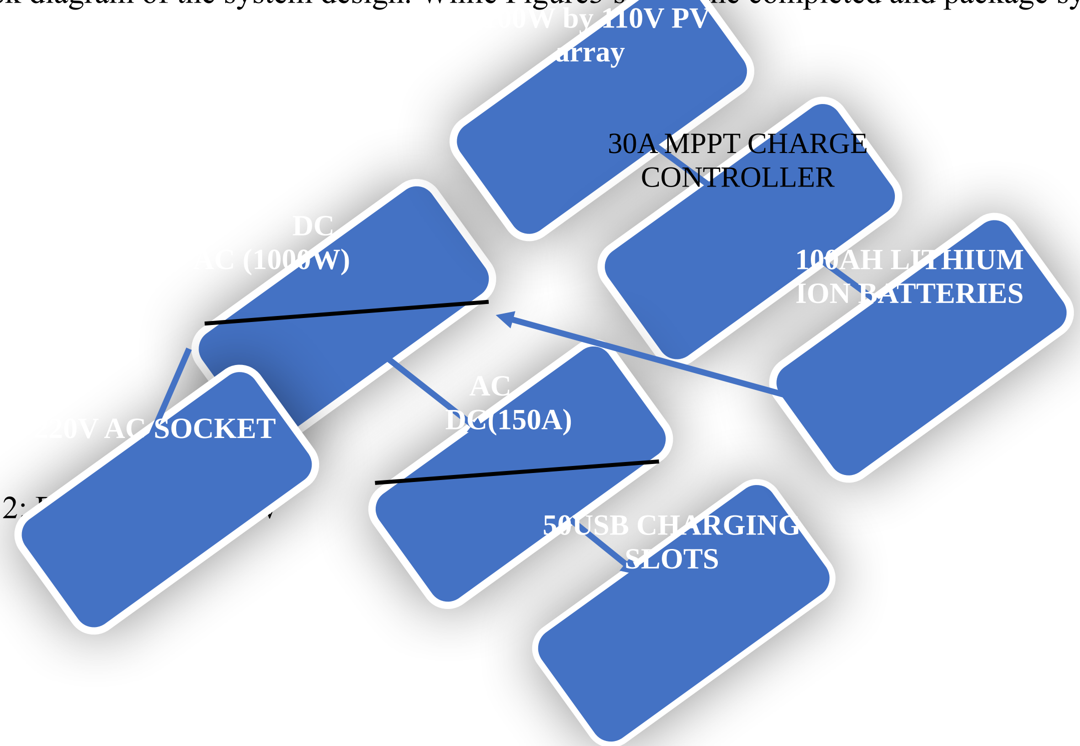

Figure 2: [illegible]

Figure 3 : Picture of the Finished and Package Product

VI. Results and Discussion

The 50-USB-slot mini solar power station was tested under various load conditions to evaluate its performance. The system was able to charge 50 smartphones simultaneously, with an average output voltage of 5.02V and current of 2A per USB port. The solar panel generated an average power of 900W, and the battery bank provided a backup time of 5 hours during low-sunlight periods. The system efficiency was calculated to be 85%. The results demonstrate the system's reliability and efficiency in providing a sustainable charging solution for mobile devices.

VII. Conclusion

The design and development of the 50-USB-slot mini solar power station has successfully addressed the need for a reliable and sustainable charging solution for mobile devices. The system's ability to charge 50 smartphones simultaneously, with a high efficiency of 85%, demonstrates its potential for deployment in public spaces, such as campuses, markets, and transport hubs. This system can economically impact positively on those already into mobile devices battery charging business, as it will drastically cut down their running cost. More so, the use of solar energy as the primary power source reduces dependency on fossil fuels and minimizes carbon emissions, promoting a cleaner and more sustainable environment. The system's robust design and electronic protection mechanisms ensure safe and reliable operation, making it an ideal solution for powering mobile devices in areas with unreliable electricity supply. Overall, the project has demonstrated the feasibility of solar-powered charging systems and has the potential to contribute to the widespread adoption of renewable energy technologies.

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