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DESIGN AND CONSTRUCTION OF A MOVABLE MODULAR ENERGY STORAGE SYSTEM FOR INSTITUTIONAL ENERGY RELIABILITY

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Abstract: Consistent electricity supply remains a major challenge in many tertiary institutions located in off grid and semi grid regions of Nigeria. Although solar photovoltaic systems are increasingly adopted as a clean energy solution, their intermittent nature limits their ability to provide uninterrupted power without adequate energy storage (Divya & Østergaard, 2009; Dunn et al., 2011). This study presents the design, construction, and performance evaluation of a movable modular energy storage system developed for the Federal College of Education (FCE), Gidan Madi, Sokoto State. The proposed system integrates electrochemical energy storage with a pure sine wave inverter housed in a compact, mobile enclosure, allowing flexible deployment across different campus locations. The system was designed to complement existing solar infrastructure and to provide temporary backup power for newly constructed facilities awaiting permanent electrification. Construction involved mechanical frame fabrication, electrical wiring, protection device integration, and thermal management provisions. Performance testing revealed a stable alternating current output of 220 V at 10 A, confirming the system's suitability for powering typical academic and administrative loads. The results demonstrate that the developed system offers a practical, scalable, and cost-effective approach to improving energy reliability in educational institutions. The study contributes to sustainable energy solutions for off grid environments and provides a replicable model for similar institutions in developing regions.

Keywords: Modular energy storage, solar energy, inverter system, renewable energy, off-grid power, educational institutions.

I. INTRODUCTION

The availability of dependable and sustainable electrical energy is a prerequisite for the smooth running of modern educational institutions. Tertiary institutions in various parts of Nigeria, especially in the remote and semi-urban regions, experience a lack of stable electrical energy due to inadequate public power supply and the availability of intermittent renewable energy sources. The Federal College of Education (FCE), Gidan Madi, Sokoto State, Nigeria, is located in a region with high solar irradiance; thus, solar photovoltaic power systems have the potential of being the main energy source for the institution (Sambo, 2009; Oluseyi et al., 2016). As a result, solar power has been adopted as the main energy source for the existing facilities. Solar power generation is dependent on environmental conditions and is greatly reduced at night and during periods of low solar irradiance. As a result, the reliability of solar power is limited in the absence of energy storage facilities (Divya & Østergaard, 2009; Dunn et al., 2011). As the institution expands with the development of additional facilities, the need for a flexible and reliable power supply system has become increasingly important. The development of permanent solar power supply systems for all the new facilities would require a lot of capital investment and time. A movable modular energy storage system has the potential of providing the required on-demand power supply where and when it is needed.

Movable and modular energy storage systems offer several advantages, including portability, scalability, and ease of integration with existing renewable energy infrastructure (Luo et al., 2015; Yang et al., 2018). By storing excess solar energy and supplying it during periods of low generation or grid failure, such systems enhance energy resilience while optimizing the utilization of renewable resources (Akinyele & Rayudu, 2014). Additionally, mobility allows a single system to serve multiple locations, making it particularly suitable for institutional environments with evolving energy demands.

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This study focuses on the design and construction of a movable modular energy storage system tailored to the operational needs of FCE Gidan Madi. The system is intended to function as a backup and transitional power solution, ensuring continuity of academic and administrative activities. Beyond addressing immediate institutional energy challenges, the project aims to demonstrate a replicable and sustainable energy storage model applicable to similar educational institutions and off-grid communities.

II. SYSTEM DESIGN AND METHODOLOGY

2.1 System Architecture

The developed system was designed as a standalone movable energy storage unit capable of operating alongside existing solar photovoltaic (PV) installations within the institution. Its primary function is to store electrical energy in a battery bank and supply AC power to loads through an inverter when required. The system architecture follows a conventional battery-based energy storage configuration widely adopted in renewable energy applications due to its flexibility and compatibility with PV systems (Divya & Østergaard, 2009; Dunn et al., 2011). The energy flow path is structured as follows: Solar PV - Charge Controller - Battery Bank - Inverter - AC Load. Figures 1 and 2 present the block diagram and electrical wiring diagram of the developed system.

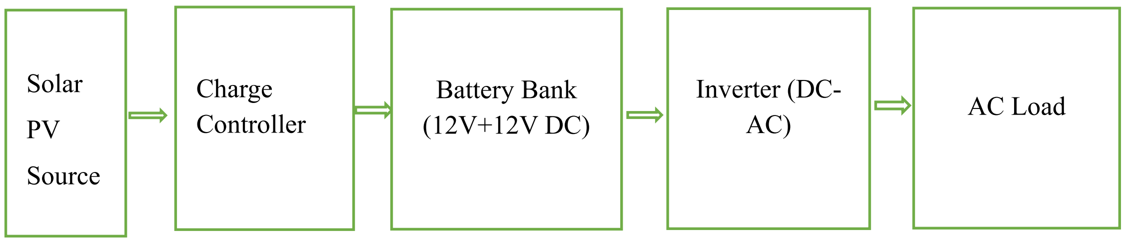

Figure 1: Block diagram of the developed movable modular energy storage system

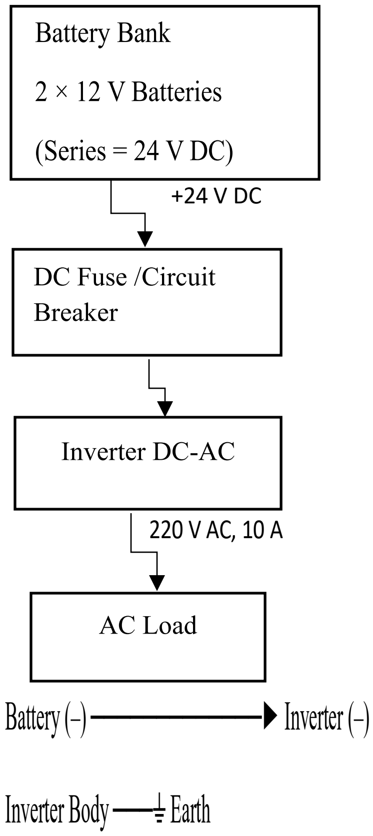

Figure 2: Electrical wiring diagram of the developed movable modular energy storage system

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The modular configuration allows each subsystem to function independently while remaining integrated within a single mobile platform.

2.2 Component Selection

System components were selected based on reliability, compatibility, and suitability for modular deployment in an institutional environment.

2.2.1 Battery Storage Unit

A battery based energy storage approach was adopted due to its technological maturity and widespread use in PV supported systems (Linden & Reddy, 2011). Two 12 V SunFit batteries were connected in series to provide a 24 V DC supply. SunFit batteries were preferred because they withstand repeated charge discharge cycles and provide stable energy output under moderate loads.

2.2.2 Inverter unit

A pure sine wave inverter was selected to convert DC power into AC power suitable for institutional loads. Pure sine wave inverters are recommended for applications involving sensitive electronic equipment due to their ability to deliver grid-quality output (Rashid, 2014).

2.2.3 Charge Controller and Protection Devices

A charge controller was incorporated to regulate battery charging and prevent overcharging or deep discharge. DC fuses, AC circuit breakers, and grounding were included to ensure operational safety and system protection (Dunn et al., 2011).

2.3 Electrical Design and Integration

The electrical wiring layout was designed to minimize voltage drop and ensure safe current-carrying capacity. Cable sizing was determined based on expected load current and inverter capacity. Proper conductor sizing is essential for minimizing energy losses and preventing overheating in renewable energy systems (Luo et al., 2015). All DC connections were insulated and polarity was verified before energizing the system. The AC output was routed through protective devices before connection to load terminals.

2.4 Mechanical Design, Construction and Testing

All components were housed within a reinforced metal enclosure fitted with heavy duty wheels to enable mobility. The batteries were positioned at the base to lower the center of gravity and improve stability during movement. Ventilation openings were provided for thermal management. The modular design allows easy maintenance and future expansion. Modular configurations are recognized for improving flexibility and scalability in decentralized energy systems (Tan et al., 2013; Yang et al., 2018). The construction process involved mechanical assembly, mounting of electrical components, and wiring according to the system design. After assembly, continuity and polarity tests were conducted before integrating the system with the solar PV source. Performance testing was then carried out under typical institutional load conditions to evaluate operational functionality. Figures 3-5 show the fabrication stages, component installation, and the completed movable modular energy storage system.

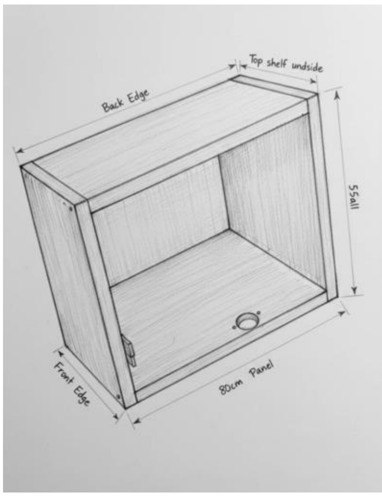

Figure 3: Enclosure cabinet drawing

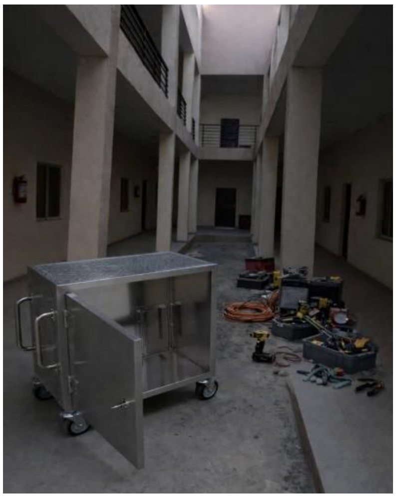

Figure 4: Mechanical enclosure and structural layout of the constructed system.

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Figure 5: Battery & inverter install.

III. EXPERIMENTAL RESULTS

Following system construction and integration, performance testing was conducted under typical institutional load conditions. The battery bank was charged using the existing solar photovoltaic installation, and the inverter output was connected to typical institutional electrical loads such as lighting systems, desktop computer, and office equipment. Measurements of output voltage and current were obtained using standard digital measuring instruments. Figures 6 - 8 show the system during performance testing and measurement of output electrical parameters.

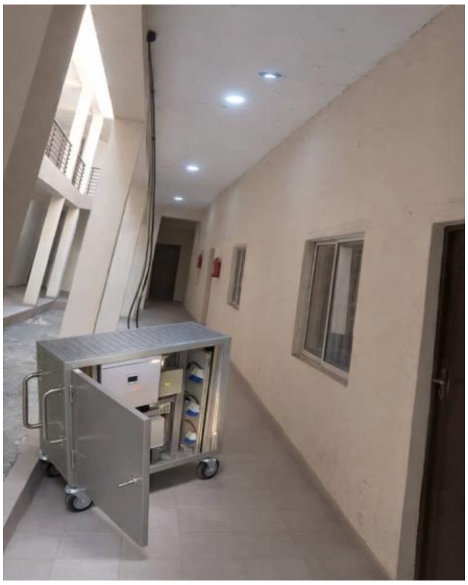

Figure 6: The developed energy storage system, powering school office

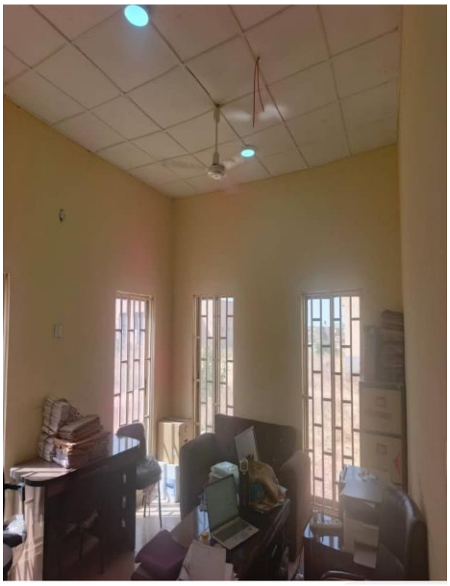

Figure 7: Lighting point been powered

Table 8 Measured electrical output parameters

Parameters	Measured Value
Output Voltage	220V (AC)
Output Current	10A
Output Power	2.2KW

During testing, the system consistently delivered an output voltage of 220 V AC and an output current of 10 A under load. These values indicate stable inverter operation and sufficient battery discharge capability during the test period.

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The output power of the system was determined using the standard electrical power relationship is: $P = VI$ Substituting the measured values to have:

$$P = 220 \times 10 = 2200 \text{ W}$$

This corresponds to an output power of approximately 2.2 kW. The system was able to support typical institutional loads such as lighting circuits, desktop computers, and office equipment without observable performance degradation. During operation, the inverter maintained a steady output voltage with no noticeable flicker or fluctuation in connected lighting loads. The batteries discharged smoothly without excessive heating, and no abnormal noise or protective device tripping was observed. These observations indicate that the electrical connections, component sizing, and protection coordination were adequate for the applied load conditions.

The test results confirm that the developed system can reliably function as a supplementary and transitional power source within the institution. The measured performance parameters demonstrate that the system meets its intended design objective of providing stable, moderate-capacity power support.

IV. DISCUSSION

The experimental results demonstrate that the developed movable modular energy storage system is capable of delivering stable AC output suitable for institutional applications. The measured output of 220 V at 10 A, corresponding to approximately 2.2 kW, confirms that the inverter and battery configuration were appropriately sized for moderate academic and administrative loads. Stable voltage output indicates effective DC-AC conversion and adequate battery discharge performance under operational conditions. The observed performance aligns with findings from previous studies that emphasize the role of battery-based storage systems in enhancing the reliability of renewable energy installations (Divya & Østergaard, 2009; Dunn et al., 2011). By integrating energy storage with existing solar photovoltaic infrastructure, the system mitigates the intermittency challenges associated with solar energy and ensures continuity of supply during low irradiance periods or temporary grid outages (Akinyele & Rayudu, 2014). One of the key contributions of this study is the mobility and modularity of the developed system. Unlike conventional stationary energy storage installations, the movable design enables flexible deployment across multiple locations within the institution. This improves resource use and reduces the need for separate backup systems for each facility. Similar advantages of modular storage architectures have been reported in decentralized and microgrid energy applications, where scalability and flexibility are essential (Tan et al., 2013; Yang et al., 2018).

Additionally, the system provides a practical alternative to fuel powered generators commonly used as backup power sources in many institutions. Generator based solutions are associated with high fuel costs, noise, and environmental emissions, whereas battery supported renewable systems offer quieter and cleaner operation. The developed system therefore supports institutional sustainability goals while improving working reliability. The results validate the feasibility of deploying movable modular energy storage as a transitional and supplementary power solution in educational institutions with expanding infrastructure. The system demonstrates how existing renewable energy resources can be better utilized through flexible storage solutions tailored to local operational needs.

V. CONCLUSION

This study presented the design and experimental evaluation of a movable modular energy storage system developed to improve power reliability in an educational institution. The system was designed to operate alongside existing solar photovoltaic installations and provide flexible, on-demand power support to facilities with limited or newly developing energy infrastructure. Experimental testing demonstrated that the system consistently delivered a stable output of 220 V AC at 10 A, corresponding to an output power of approximately 2.2 kW. The stable voltage profile and absence of abnormal operational behavior during testing confirm that the inverter, battery configuration, and protection devices were appropriately selected and integrated. The system effectively supported typical institutional loads such as lighting and office equipment, validating its suitability as a supplementary and transitional energy solution.

A key input of this work is the mobility and modular design of the developed system. Unlike conventional stationary energy storage installations, the movable configuration allows deployment across multiple locations, improving resource utilization and reducing the need for separate backup systems for each facility. This feature makes the system particularly relevant for institutions with expanding infrastructure and evolving energy demands.

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The results demonstrate that movable modular energy storage systems offer a practical, cost-effective, and sustainable approach to enhancing energy reliability in educational environments. Future work may focus on long term performance monitoring, capacity scaling through additional battery modules, and integration with smart energy management systems.

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