Hybrid Sand and Gravity Battery for Automatic Switching Based on High Power Availability

AJAY KUMAR[1], NISHAL[2], SENHA[3], BHUVANASHREEHI[4]
[1, 2, 3, 4]*Member, Department of EEE, Dayananda Sagar Academy of Technology & Management*

***Abstract*—This paper presents the development and implementation of a hybrid energy storage system combining a sand battery and a gravity battery. The system includes an automatic switching mechanism based on the power availability from each unit. The sand battery stores thermal energy using silica, while the gravity battery utilizes gravitational potential energy with mass elevation. A microcontroller-based monitoring system tracks real-time energy data and activates the battery that generates higher output at any given time. This approach enhances energy reliability and efficiency in renewable-based systems and offers a sustainable storage alternative.**

***Indexed Terms*—Automatic switching, energy storage, gravity battery, hybrid system, sand battery**

I. INTRODUCTION

With the growing dependency on renewable energy sources such as solar and wind, the energy sector faces a major challenge: intermittency in energy supply. Unlike traditional fossil-fuel-based power generation, renewable sources are not continuously available, leading to fluctuations in energy production. To bridge the gap between generation and consumption, efficient energy storage systems are indispensable. Among the newer advancements in energy storage technologies, sand and gravity batteries have emerged as promising alternatives.

Sand batteries store thermal energy by heating large volumes of silica sand to high temperatures, making use of its excellent heat retention properties. This stored energy can later be converted into electrical energy using thermoelectric converters or through heat transfer mechanisms. Gravity batteries, on the other hand, store potential energy by elevating a mass. When energy is needed, the mass is allowed to fall, turning a generator and producing electricity.

This research introduces a hybrid configuration that intelligently combines both technologies into a single framework. The innovation lies in the automatic switching algorithm that monitors power availability from both systems and dynamically switches the load to the most efficient source. This not only enhances reliability but also increases the overall efficiency of the system.

The hybrid system is especially suitable for rural and off-grid applications where energy demand varies and infrastructure limitations exist. Furthermore, it opens new avenues for integrating thermal and mechanical storage mechanisms with digital automation.

II. LITERATURE REVIEW

Several studies have highlighted the limitations of conventional battery systems, such as high cost, environmental hazards, and limited life cycles. Sand batteries, as explored in the work of A. Smith et al. [1], provide a thermally stable and cost-effective method of energy storage using abundant materials like silica. The concept of gravity energy storage was thoroughly discussed by R. Taylor [2], where gravitational potential is utilized for energy retention with relatively low losses.

Other researchers, such as Brown and Liu [3], investigated the integration of IoT for real-time monitoring and automation in hybrid systems. These works suggest that smart monitoring and control mechanisms are critical in optimizing hybrid energy architectures. D. Green [4] proposed intelligent switching systems that prioritize available power sources based on output efficiency, laying the groundwork for automated hybrid energy management.

Despite individual advancements in thermal and mechanical storage technologies, there remains limited research on combining these technologies into a seamless and automatically managed hybrid system. This study attempts to fill this gap by introducing an integrated model enhanced with intelligent switching and control.

III. SYSTEM DESIGN

A. Sand Battery Mechanism

The sand battery system is constructed using high-purity silica sand enclosed in an insulated steel container. Electric heating coils are embedded to raise the temperature of the sand to over 500°C. The thermal energy is stored and retained for several hours. When energy is required, the stored heat is extracted using a heat exchanger and converted into electricity using thermoelectric generators. The advantages of sand as a storage medium include its low cost, abundance, non-toxicity, and thermal stability.

B. Gravity Battery Mechanism

The gravity battery consists of a heavy mass suspended by a motor-driven pulley system. Excess electricity from renewable sources is used to lift the mass to a certain height, storing energy in the form of gravitational potential energy. When power is needed, the mass is lowered, and the resulting motion drives a DC generator to produce electricity. The mechanical components are built to reduce friction and improve conversion efficiency.

C. Control System

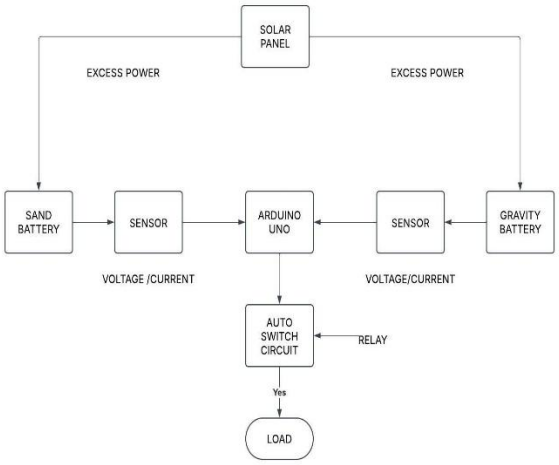
A microcontroller, typically an Arduino or STM32, is used to manage the sensors and relays. Voltage and current sensors are connected to each battery system. The controller continuously reads data and determines which battery is generating higher power at any given moment. A logic circuit with relay drivers ensures seamless switching without affecting the output load. The control system also includes thermal sensors for safety and performance optimization.

IV. METHODOLOGY

The hybrid energy system is designed to operate under various load and generation conditions. The following steps outline the methodology:

1. System Setup: Sand battery and gravity battery units are constructed and integrated with their respective energy conversion systems.
2. Sensor Deployment: Voltage, current, and temperature sensors are installed on both systems.
3. Microcontroller Programming: A C/C++ program is uploaded to the microcontroller to monitor sensor readings and implement the switching algorithm.
4. Switching Logic: The algorithm compares instantaneous power output (Voltage × Current) from each battery and selects the source with higher availability.
5. Load Activation: Based on the output of the logic block, a relay circuit connects the selected battery to the load.
6. Optional IoT Integration: A GSM or Wi-Fi module is used to send data logs to a remote server or smartphone app, enabling remote monitoring.

V. BLOCK DIAGRAM



VI. RESULTS AND DISCUSSION

Initial lab-scale tests were conducted using a 100W heating coil for the sand battery and a 25kg mass for the gravity battery. The sand battery demonstrated the ability to store energy for up to 8 hours with minimal heat loss, and the gravity battery was capable of generating short bursts of electricity depending on the drop height.

The automatic switching system was tested under simulated fluctuating conditions. The microcontroller successfully identified the higher energy source and switched loads within milliseconds, ensuring uninterrupted power delivery. Data logs showed improved system efficiency and reliability compared to single-source setups. Energy loss during switching was found to be negligible.

Key observations include:

- Sand battery performs better for long-duration low-load applications.
- Gravity battery is suitable for short-duration high-power demands.
- Combined usage covers a wider range of energy requirements.

CONCLUSION

The development of a hybrid sand and gravity battery system with automatic switching offers a new dimension to renewable energy storage. This configuration ensures optimal utilization of stored energy by dynamically adapting to real-time conditions. The integration of thermal and mechanical storage in a single framework addresses the limitations of individual systems, making the solution more versatile and efficient.

Applications of this technology range from residential microgrids to rural electrification and backup power systems in industries. Future work will focus on scaling the model, improving conversion efficiency, and incorporating machine learning for predictive switching.

FUTURE SCOPE

There are several avenues to further enhance the proposed hybrid energy storage system:

1. Scaling for Commercial Use: The current setup is designed for lab-scale demonstration. Scaling up the system to handle kilowatt or megawatt-level loads can facilitate industrial and grid-level integration.
2. Advanced Control Algorithms: Machine learning and AI-based decision-making can be implemented for predictive load management and optimization.
3. Energy Conversion Efficiency: Research can focus on improving the efficiency of heat-to-electricity and mechanical-to-electrical energy conversion techniques.
4. Modular Design: Modularization of the hybrid system can enable flexible deployment in various terrains and use-cases such as disaster recovery, military operations, and mobile charging stations.
5. Environmental Monitoring: Integration of environmental data (weather patterns, solar intensity) can help anticipate energy availability and dynamically adapt the storage strategy.

By addressing these directions, the hybrid sand and gravity battery system could become a cornerstone technology in the sustainable energy ecosystem.

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