Electricity Generation Using Gravity Battery

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DECLARATION

We certify that the project-based thesis titled "Electricity Generation Using Gravity Battery" is completely our group work. All sources of information and knowledge used in this paper that were obtained from other researchers have been properly acknowledged through appropriate references.

All materials used in this work, including images, figures, tables, and citations, have been reviewed and approved by our supervisor.

We hereby declare that this thesis has not been previously submitted, either in whole or in part, for the award of any degree or for publication elsewhere.

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CERTIFICATION

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Abstract

This project explores an innovative and sustainable method of electricity generation using a gravity battery system. The concept is based on storing energy in the form of gravitational potential energy by lifting a mass to a certain height and converting it back into electrical energy as the mass descends. When excess energy is available, it is used to elevate a heavy object, and during periods of demand, the stored energy is released by allowing the object to fall, driving a generator to produce electricity.

The gravity battery system offers a clean, renewable, and efficient alternative to conventional energy storage technologies such as chemical batteries. It reduces environmental impact, requires minimal maintenance, and has a longer operational lifespan. This project highlights the working principles, design considerations, advantages, and potential applications of gravity-based energy storage, particularly in supporting renewable energy sources like solar and wind power.

Overall, gravity batteries present a promising solution for sustainable energy storage and contribute to the development of eco-friendly power generation systems.

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Introduction

1.Introduction

Energy is the fundamental requirement for the socio-economic development of any country. With the global shift towards renewable energy sources like solar and wind, the challenge of energy intermittency has become more prominent. To address this, efficient energy storage systems are essential. The "Gravity Battery" project presents an innovative and sustainable approach to storing and retrieving electricity by utilizing the simple force of gravity.

A gravity battery is a type of energy storage device that stores electrical energy in the form of gravitational potential energy. This project revolves around a unique mechanical and electronic setup that employs a concrete box or heavy mass, a pulley and chain mechanism, and a DC gear motor acting as a generator. The core objective of this system is to provide a cost-effective, long-duration energy storage solution that can enhance grid stability and facilitate better integration of renewable energy.

The operational mechanism starts with solar panels, which convert sunlight into electrical energy. This energy is then regulated through a buck converter and stored in a chemical battery. Using an Arduino UNO microcontroller and an L298N motor driver, the system controls a gear motor to lift a heavy load, thereby converting electrical energy into potential energy. When power is required, the load is allowed to descend under gravity, rotating the motor to generate electricity once again.

This project demonstrates a reliable prototype with practical feasibility for real-world applications. By repurposing infrastructure and focusing on sustainability, gravity batteries offer a promising future for delivering electricity to remote or underserved areas while minimizing energy losses.

1.1 Introduction Of Things

The global energy landscape is currently undergoing a significant transformation, moving away from fossil fuels toward cleaner, renewable sources such as solar, wind, and hydroelectric power. However, the inherent intermittency of renewable energy where power generation depends on weather conditions and time of day poses a major challenge for grid stability. This has created an urgent need for efficient, scalable, and cost-effective energy storage systems (ESS).

While lithium-ion batteries are widely used, they face limitations regarding life cycle, environmental impact of mining, and high costs for long-duration storage. In this context, Gravity Energy Storage (GES), commonly known as a Gravity Battery, emerges as a compelling alternative. A gravity battery is a type of energy storage device that stores electrical energy in the form of gravitational potential energy.

The fundamental principle of this project is based on the simple physics of lifting and dropping a mass. During periods of excess energy (such as peak solar production), the system uses an electric motor to lift a heavy concrete block or mass to a certain height, effectively "charging" the battery by storing potential energy ($E_p = mgh$). When demand increases or renewable supply drops, the mass is released in a controlled manner. As gravity pulls the mass down, it drives a generator to produce electricity, which is then fed back into the circuit or grid.

This project, developed at Sonargaon University, focuses on designing a prototype that integrates an Arduino UNO microcontroller, Solar PV technology, and a Gear Motor mechanism. By utilizing locally available materials and automated control systems, this project aims to demonstrate a sustainable and infrastructure-friendly solution for the future of energy storage, particularly for remote areas and grid stabilization.

1.2 Purpose of the Study

The primary purpose of this study is to design and implement a functional prototype of a Gravity Battery system that can effectively store and release energy. As the world transitions toward renewable energy, the need for reliable storage becomes critical. This study aims to explore a mechanical alternative to chemical batteries, focusing on the following core purposes:

- **Exploring Sustainable Storage Solutions:** To investigate how gravitational potential energy can serve as a clean and sustainable medium for long-term energy storage without the environmental hazards associated with chemical battery disposal.

- **Cost-Effective Energy Management:** To demonstrate a system that uses relatively low-cost materials (like concrete, pulleys, and gear motors) to provide an affordable electricity storage and generation solution, especially for large-scale applications.

- **Addressing Renewable Intermittency:** To create a mechanism that can store excess energy produced by solar panels during the day and discharge it during peak demand or nighttime, ensuring a steady power supply.

- **Enhancing Grid Stability:** To analyze how gravity-based systems can respond to fluctuations in the power grid by providing quick-discharge energy when needed, thereby improving overall grid reliability.

- **Technical Implementation and Automation:** To integrate modern electronic components like the Arduino UNO, buck converters, and motor drivers to automate the energy conversion process and monitor performance in real-time.

By achieving these purposes, the study seeks to validate the feasibility of gravity batteries as a viable component of the future energy infrastructure, particularly in regions where traditional storage technology might be too expensive or difficult to maintain.

1.3 Statement of the Problem

The world is rapidly moving toward renewable energy sources, but this transition faces a critical obstacle: the lack of efficient and sustainable energy storage. The core problems that this project addresses are as follows:

- **Intermittency of Renewable Energy:** Solar and wind energy are not available 24/7. Without an effective storage system, excess energy produced during the day (for solar) or windy periods is wasted, leading to power shortages when the sun goes down or the wind stops.

- **Environmental Impact of Chemical Batteries:** Traditional energy storage relies heavily on Lithium-ion or Lead-acid batteries. These batteries have a limited lifespan, involve hazardous mining processes, and pose significant environmental risks during disposal.

- **High Cost of Long-Duration Storage:** Large-scale chemical battery plants are extremely expensive to build and maintain. For developing regions or remote areas, these costs are often prohibitive, making it difficult to achieve energy independence.

- **Grid Instability:** Rapid fluctuations in energy demand can cause instability in the electrical grid. Current systems often struggle to provide an immediate and mechanical response to these fluctuations without significant energy loss.

- **Lack of Simple Mechanical Solutions:** While pumped hydro storage exists, it requires specific geographical features (like mountains and large water bodies). There is a lack of localized, mechanical storage solutions that can be implemented in urban or flat terrain using simple infrastructure.

1.4 State-of-the-art Solutions

The field of energy storage is currently dominated by electrochemical batteries, but recent advancements have introduced several "state-of-the-art" mechanical solutions that are gaining global attention. This project is inspired by and contributes to these modern engineering approaches:

- **Solid Mass Gravity Energy Storage (GES):** Modern companies like *Energy Vault* have pioneered the use of multi-armed cranes and composite blocks. These systems use excess renewable energy to stack heavy blocks in a tower, storing potential energy that is later released as the blocks are lowered. Our project utilizes a similar concept using a concrete mass and a pulley system.

- **Abandoned Mine Shaft Utilization:** A cutting-edge solution involves repurposing decommissioned deep mine shafts. By suspending heavy weights in these shafts, massive amounts of energy can be stored without occupying surface space. Companies like Gravidity are currently leading this research.

- **Pumped Hydro Storage (PHS):** While an older technology, modern PHS remains the most widely used large-scale storage. However, its requirement for specific geography makes it less flexible than the modular gravity battery prototype developed in this study, which can be implemented in diverse environments.

- **Hybrid Renewable Integration:** Current state-of-the-art systems often combine solar PV with smart controllers. Our prototype integrates an **Arduino UNO** and **Buck Converter** to manage solar charging efficiently, aligning with modern trends in smart-grid technology.

- **Comparison with Lithium-ion Technology:** Unlike chemical batteries that degrade over time (usually 5–10 years), mechanical gravity batteries offer a lifespan of 25–50 years with minimal maintenance. This durability is a key feature of modern mechanical storage research aimed at reducing the carbon footprint of energy infrastructure.

By implementing this prototype, we are exploring a localized and automated version of these global state-of-the-art technologies, focusing on accessibility and mechanical simplicity.

1.5 Scope of the Work

The scope of this work focuses on the design, development, and performance analysis of a prototype Gravity Battery system. It encompasses both the mechanical structure and the electronic control units required for energy conversion. The key areas covered under the scope of this project include:

- **Design and Prototype Development:** Creating a physical model using a concrete mass, a pulley-chain system, and a stable frame to demonstrate the storage of gravitational potential energy.
- **Integration of Renewable Energy:** Utilizing Solar Photovoltaic (PV) panels as the primary source of energy to "charge" the system, showcasing the synergy between solar power and mechanical storage.
- **Automation and Control**: Implementing an Arduino UNO microcontroller to manage the charging and discharging cycles, including the use of an L298N motor driver to control the direction and speed of the gear motor.
- **Power Regulation:** Integrating a Buck Converter to ensure a stable voltage supply from the solar panel to the battery and control circuits, preventing damage to sensitive electronic components.
- **Real-time Monitoring:** Incorporating a 16×2 LCD display and sensors to provide real-time feedback on the system’s status, such as whether the load is ascending (charging) or descending (discharging).
- **Performance Evaluation:** Analyzing the efficiency of energy conversion from electrical to potential energy and back to electrical energy, and identifying the factors that influence the overall output.

Applicability Analysis: Assessing the potential for scaling this technology for residential use, small-scale industrial backup, or remote area power supply were chemical battery

- **maintenance is difficult:**

The scope is limited to a laboratory-scale prototype intended for educational and research purposes, providing a foundation for future large-scale energy storage implementations.

1.6 Design Goals

The design goals of the "Gravity Battery" project are centered on creating a reliable, efficient, and sustainable mechanical energy storage system. The specific goals are discussed below:

- **Mechanical Reliability and Structural Integrity:** One of the primary goals is to design a robust mechanical framework capable of supporting a heavy concrete mass. The pulley and chain mechanism must operate with minimal friction and maximum safety to ensure consistent energy conversion cycles.

- **Efficient Energy Conversion:** A key objective is to optimize the conversion process—from electrical energy (solar) to potential energy (lifting the mass), and back to electrical energy (descending mass). The goal is to minimize energy loss during these transitions by selecting high-quality gear motors and efficient pulley ratios.

- **Seamless Integration with Renewable Energy:** The system is designed to work in harmony with Solar Photovoltaic (PV) technology. A major goal is to ensure that the charging cycle is perfectly synchronized with solar availability, utilizing a Buck Converter to maintain a stable power flow.

- **Automation through Smart Control:** To make the system user-friendly and autonomous, a significant design goal is the implementation of an **Arduino UNO** based control logic. This allows the system to automatically switch between charging and discharging modes based on energy availability and demand without manual intervention.

- **Real-time System Monitoring:** Providing transparency in operation is a crucial goal. By integrating a **16x2 LCD display**, the design aims to offer real-time data regarding the system's status, ensuring that users can monitor the charging progress and energy generation at any moment.

- **Sustainability and Eco-friendliness:** Unlike chemical batteries, the design goal here is to use environmentally benign materials like concrete and steel. This ensures the system has a long operational life (20+ years) and does not contribute to hazardous waste at the end of its life cycle.

- **Scalability and Versatility:** The prototype is designed with the goal of being scalable. While the current model is a laboratory-scale prototype, the underlying engineering principles are intended to be applicable for larger residential or industrial energy storage needs.

By adhering to these design goals, the project aims to present a viable and innovative solution to the modern challenges of energy storage and grid management.

1.7 Project Outline/ Organization

This thesis is organized into several chapters, each detailing a specific aspect of the Gravity Battery project. The structure of the book is as follows:

- **Chapter 1: Introduction** – This chapter provides a general overview of the project, including the problem statement, objectives, the purpose of the study, and the design goals. It sets the context for the necessity of gravitational energy storage in today's renewable energy landscape.
- **Chapter 2: Literature Review** – This section explores the existing technologies in energy storage, comparing chemical batteries with mechanical systems. It also discusses the historical background and modern "state-of-the-art" solutions currently being used worldwide.
- **Chapter 3: Methodology and Design** – This chapter dives deeper into the system architecture. It includes a complete description of the methodology, the list of hardware components (such as Arduino, Solar Panels, and Gear Motors), and the structural design of the pulley-chain

mechanism.

- **Chapter 4: Implementation and Results** – This part focuses on the technical execution, featuring the circuit diagrams, block diagrams, and the working principle of the prototype. It also presents the results obtained during testing and provides an interpretation of the system's efficiency.
- **Chapter 5: Conclusion and Future Work** – The final chapter summarizes the findings of the project. It discusses the limitations of the current prototype and suggests further scopes for research and potential large-scale development in the future.

Chapter 2

Background and Motivation

2.1 Introduction

The global energy sector is currently facing two major challenges: the rapid depletion of fossil fuels and the urgent need to reduce carbon emissions to combat climate change. As a result, there has been a massive shift toward renewable energy sources, particularly Solar Photovoltaic (PV) and Wind energy. However, these energy sources are inherently intermittent—solar power is only available during the day, and wind power fluctuates unpredictably. This creates a "supply-demand gap" that can only be bridged by efficient and scalable energy storage systems (ESS).

Historically, energy storage has been dominated by Pumped Hydro Storage (PHS) and, more recently, by Electrochemical Batteries (like Lithium-ion). While PHS is efficient, it requires specific geographical terrains and massive water resources. On the other hand, chemical batteries involve complex chemical reactions, have a limited life cycle, and pose significant environmental risks due to toxic waste.

This chapter explores the background of energy storage technologies and the fundamental physics behind gravitational energy. The motivation for this project stems from the need for a "cleaner" mechanical alternative that is independent of geography and has a long operational lifespan. By understanding the limitations of current technologies, we can better appreciate the role of Gravity Batteries as a sustainable and cost-effective solution for future energy grids. This section will delve into the core concepts that inspired the design and implementation of our prototype at Sonargaon University.

2.2 Literature Review

Gravity-based energy storage has emerged as a promising solution for addressing the intermittency of renewable energy sources such as solar and wind. Unlike conventional electrochemical batteries, gravity batteries store energy by lifting a mass and releasing it to generate electricity when required. This concept has gained increasing attention in recent years due to its sustainability, long lifecycle, and low environmental impact.

Early research in gravity energy storage primarily focused on pumped hydro storage systems, where water is pumped to an elevated reservoir and released to generate electricity during peak demand periods. Although highly efficient, these systems are geographically constrained and require large-scale infrastructure [1].

To overcome such limitations, recent studies have explored solid mass-based gravity storage systems. These systems use heavy blocks or weights that are lifted using excess electrical energy and released to drive generators. Companies such as Energy Vault have developed innovative tower-based systems that demonstrate the feasibility of large-scale gravity storage [2].

In addition to mechanical design, modern research emphasizes automation and intelligent control. Microcontroller-based systems, particularly those using Arduino Uno, have been widely implemented for small-scale prototypes. These systems integrate sensors such as LDRs and limit switches to automate lifting and energy generation processes, improving efficiency and reliability [3].

Furthermore, recent advancements incorporate Internet of Things (IoT) technologies, enabling remote monitoring and control of gravity battery systems. Wireless communication modules such as Bluetooth and Wi-Fi allow users to interact with the system in real time, enhancing usability and system performance [4].

Despite these advancements, several challenges remain. Studies have reported energy losses due to mechanical friction, lower energy density compared to chemical batteries, and limitations in small-scale implementations [5]. Additionally, the integration of efficient load management and automation in a single system remains an area requiring further research.

This project addresses these gaps by developing an automated gravity battery system with integrated load control and Bluetooth-based operation. The system demonstrates a practical and cost-effective approach to renewable energy storage and utilization

2.1 Summary

In summary, this chapter established the foundational background and the core motivation behind the development of the Gravity Battery project. We have explored the critical need for energy storage systems (ESS) in the modern era of renewable energy, highlighting how traditional storage methods like chemical batteries and pumped hydro storage face significant limitations in terms of environmental impact, cost, and geographical requirements.

The motivation for this study is rooted in the quest for a sustainable, long-lasting, and eco-friendly mechanical alternative. By leveraging the fundamental physics of gravitational potential energy—storing power by lifting a mass and generating electricity as it descends—this project aims to bridge the gap between energy supply and demand. Furthermore, the integration of automation through Arduino and solar energy demonstrates a forward-thinking approach to localizing grid stability and energy independence. This background serves as the technical and conceptual framework upon which the subsequent design and methodology of the prototype are built.

2.1.1 Microcontroller-Arduino Uno

The Arduino Uno is the central controller of the gravity battery system. It is an open-source microcontroller board based on the ATmega328P, used to automate and manage the entire operation of the system. In this project, the Arduino Uno plays a crucial role in controlling both the energy storage (lifting phase) and energy generation (falling phase) processes of the gravity battery.

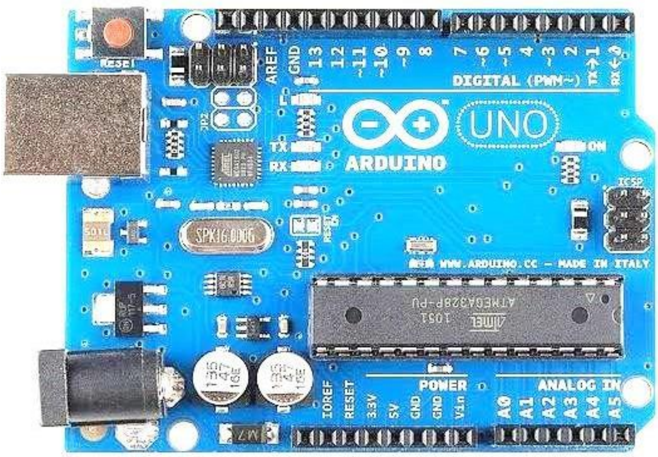


Figure 2.1: Microcontroller-Arduino Uno

2.1.2 DC Motor

The DC Motor / Generator is one of the most important components in the gravity battery system, as it enables the conversion between electrical and mechanical energy. It operates based on the principles of electromagnetic induction and Lorentz force. In this project, a single DC machine is used for both motor operation (lifting phase) and generator operation (energy generation phase), making the system cost-effective and efficient.

Figure 2.2: 12v DC Motor

2.1.3 Motor Driver (L298N)

The **L298N Motor Driver** is an essential component in the gravity battery system, used to control the operation of the DC motor. Since the Arduino Uno cannot directly supply sufficient current to drive a motor, the L298N module acts as an interface between the Arduino and the motor.

It is a **dual H-bridge motor driver**, which allows control of motor direction and speed.

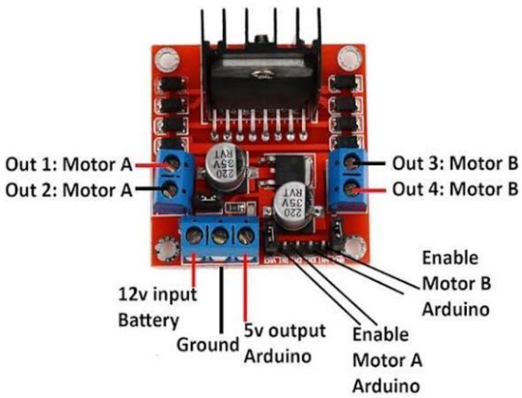


Figure 2.3: Motor Driver (L298N)

2.1.4 Servo Motor

The **servo motor** is an important component in the gravity battery system, used to control the **locking and unlocking mechanism** of the weight. It is a type of rotary actuator that allows precise control of angular position.

In this project, the servo motor ensures that the lifted mass remains securely held at the top position and is released at the correct time for energy generation.

Figure 2.4: Servo Motor

2.1.5 Buck converter

In the gravity battery system, the electrical energy is generated by a DC motor operating as a generator when the weight descends. However, the output voltage from the generator is not constant; it varies depending on the speed of rotation and load conditions. To ensure a stable and usable voltage, a **buck converter (DC-DC step-down converter)** is used.

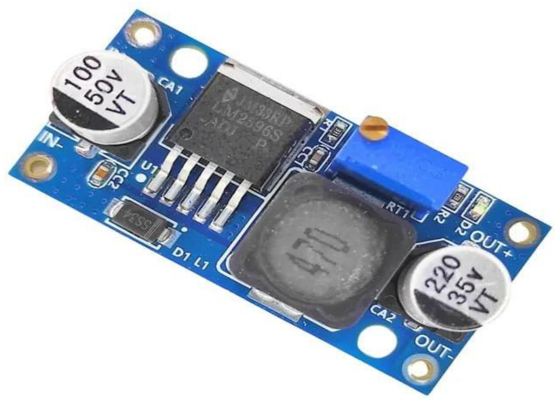


Figure 2.5: Buck converter

2.1.6 LDR Sensor

The LDR (Light Dependent Resistor) detects light intensity. It helps the system identify day and night conditions. The system lifts the weight during the day and generates electricity at night.

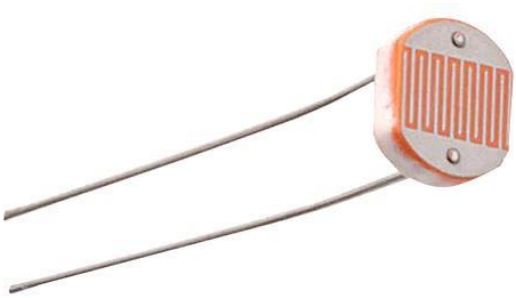


Figure 2.6: Capacitive Touch Sensors

2.1.7Solar Panel

Figure 2.7: Solar Panel

Solar panels convert sunlight into electricity using a process called the **Photovoltaic Effect**. Here is a concise, original summary of how they function:

1. Energy Absorption

Solar panels consist of **silicon cells**. When sunlight hits these cells, the energy (photons) knocks electrons loose from the silicon atoms.

2. Electricity Generation

These loose electrons are captured and forced to flow in one direction, creating **Direct Current**

(DC) electricity.

3. Power Conversion

Since most buildings run on **Alternating Current (AC)**, the DC power is sent to an **Inverter**. This device converts the electricity into a usable form for your appliances.

4. Distribution

The converted AC power flows through your electrical breaker panel to power your lights and machines. Any extra energy can be stored in batteries or sent back to the main power grid.

Summary of Benefits:

- **Renewable:** Uses infinite energy from the sun.
- **Clean:** No emissions or noise during operation.
- **Efficient:** Reduces monthly utility bills significantly.
-

2.1.8Limit Switch

Figure 2.8: Limit Switch

A limit switch is an electromechanical device operated by the physical force exerted on it by a moving object. It is used to detect the presence, absence, or position of an object to control an electrical circuit.

Its operation can be broken down into three simple steps:

- **Normal State (Rest Position):** When no external force is applied to the roller lever, the switch remains in its default state. In this position, the **COM (Common)** terminal is internally connected to the **NC (Normally Closed)** terminal, allowing current to flow through that path, while the **NO (Normally Open)** terminal remains disconnected.

- **Actuation (Triggered Position):** As a moving object or machine part makes physical contact with the roller lever, it depresses the lever. This mechanical movement triggers an internal spring mechanism, causing a rapid shift in the electrical contacts (known as a snap-action).
- **Circuit Switching:** Once actuated, the internal contact instantly snaps away from the **NC** terminal and connects to the **NO** terminal. This action changes the state of the circuit—either stopping a motor, changing machine speed, or triggering a safety alarm.

When the moving object recedes and releases the lever, the internal return spring automatically forces the contacts back to their original "Normal State."

Key Application: These switches are widely used in industrial automation, safety interlocks, conveyors, and elevators to safely manage machine travel limits and prevent mechanical overruns.

2.1.9 2-Channel Relay Module

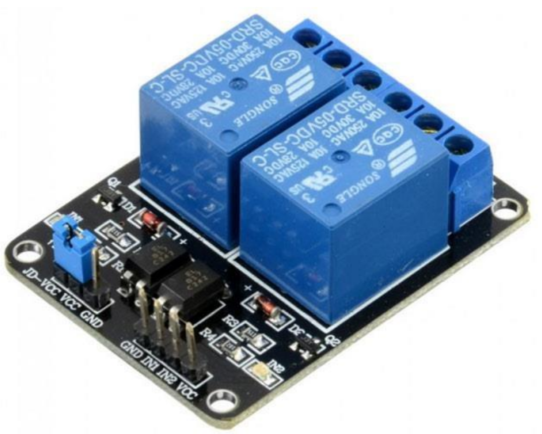


Figure 2.9: 2-Channel Relay Module

A relay module is an electrically operated switch that allows a low-power signal (like from a microcontroller or PLC) to safely control high-voltage, high-current circuits (like motors, lights, or appliances). Since this is a **2-channel module**, it contains two independent relay units that can control two separate loads simultaneously.

Its operation relies on isolation and electromagnetism, functioning through the following steps:

- **Control Signal Input (Low-Voltage Side):** The control side operates on a low voltage (typically 5V). When a trigger signal is sent to the input pins (**IN1** or **IN2**), it passes through an **optocoupler** (the small black 4-pin ICs on the board). The optocoupler provides optical isolation, protecting your sensitive control electronics from any high-voltage spikes on the relay side.

- **Electromagnetic Actuation:** The isolated signal activates an internal transistor, which allows current to flow through the relay's internal copper coil. This current flow generates a magnetic field, turning the coil into a temporary electromagnet.
- **Contact Switching (High-Voltage Side):** The magnetic force pulls a movable iron armature inside the blue housing. This physical movement changes the connection state of the output terminal block:
    - **Normal State (No Signal):** The **COM (Common)** terminal is connected to the **NC (Normally Closed)** terminal.
    - **Actuated State (Signal Applied):** The armature snaps away from NC and connects the **COM** terminal to the **NO (Normally Open)** terminal, completing the high-voltage circuit and powering up the connected load.

Once the control signal is removed, the magnetic field collapses, and an internal spring instantly pulls the armature back to its default **NC** position.

Key Feature: The blue jumper on the left (**JD-VCC / VCC / GND**) allows you to completely separate the power supply of the relay coils from the microcontroller's power supply, ensuring maximum electrical safety and noise reduction.

2.1.10 16x2 Character LCD Display

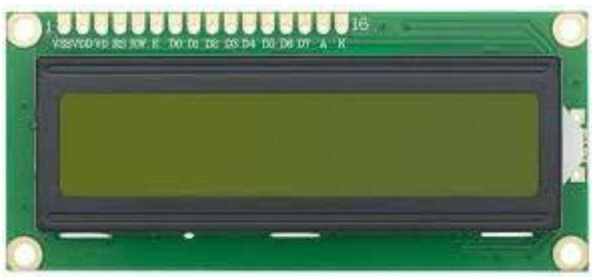


Figure 2.10: 16x2 Character LCD Display

A 16x2 LCD (Liquid Crystal Display) is an electronic visualization module used to display alphanumeric characters, symbols, and custom glyphs. It can show two rows of text, with up to 16 characters per row. The module operates based on modulating light through liquid crystals managed by an onboard controller (typically the industry-standard HD44780 driver).

Its internal mechanism and operation function through the following steps:

- **Liquid Crystal Manipulation:** The display consists of millions of liquid crystal molecules sandwiched between two polarizing filters. In their natural state, these crystals allow light from the LED backlight (connected via **A**node and **K**athode pins) to pass through, keeping the screen bright.
- **Pixel Activation (Character Matrix):** Each character on the screen is made up of a grid of tiny pixels (usually a 5×8 or 5×11 dot matrix). When a microcontroller sends data, the onboard LCD driver applies an electric voltage to specific pixels in the grid. This voltage twists the liquid crystal molecules, causing them to block the backlight in those exact spots, rendering visible dark characters against a illuminated background.
- **Control and Data Processing:** The module relies on 16 external interface pins to communicate:
  - **Power & Contrast: VSS** (Ground), **VDD** (+5V), and **V0** (Contrast adjust pin, usually connected to a potentiometer).
  - **Control Pins: RS** (Register Select) toggles between sending commands (like clearing the screen) or actual data. **RW** (Read/Write) selects data direction, and **E** (Enable) acts as a clock latch to trigger data processing.
  - **Data Bus:** Pins **D0 to D7** carry the binary ASCII codes of the characters from the host controller to the display. It can operate in either an 8-bit mode (using all 8 data lines) or a 4-bit mode (using only D4 to D7 to save microcontroller pins).

Key Feature: The onboard controller contains a built-in ROM that maps standard ASCII characters directly to their corresponding dot-matrix patterns, significantly reducing the processing load on your external microcontroller.

2.1.11 LED

Figure 2.11: LED

An LED is a semiconductor light source that emits light when an electric current flows through it. It operates on the principle of **electroluminescence**.

Its core mechanism works in three brief steps:

- **PN Junction Setup:** The LED contains a p-type semiconductor (filled with holes) and an n-type semiconductor (filled with electrons) joined together.
- **Forward Biasing:** When a voltage is applied in the forward direction (connecting the longer lead/Anode to positive and shorter lead/Cathode to negative), electrons and holes are pushed toward the junction.
- **Photon Emission:** At the junction, the electrons recombine with the holes. As electrons drop into a lower energy state during this recombination, they release their excess energy in the form of light particles (**photons**).

Note: The specific chemical composition of the semiconductor material determines the exact bandgap energy, which dictates the color (wavelength) of the emitted light

2.1.12 Lead-Acid Battery

Figure 2.12: Lead-Acid Battery

A lead-acid battery is a reversible electrochemical device that stores electrical energy as chemical energy. It operates on the principle of a reversible chemical reaction between lead plates and an electrolyte solution.

Its core mechanism relies on two modes of operation:

- **Discharging State (Powering a Load):**
  - **The Setup:** Inside the battery, the positive plate is made of Lead Dioxide (PbO_2), the negative plate is Sponge Lead (Pb), and both are submerged in an electrolyte of diluted Sulfuric Acid (H_2SO_4).
  - **The Reaction:** When an external electrical load is connected, a chemical reaction occurs. The sulfuric acid reacts with both plates, converting them into Lead Sulfate ($PbSO_4$).
  - **Electron Flow:** This reaction releases free electrons at the negative terminal. The electrons flow through the external circuit to the positive terminal, creating an electric current. As a byproduct, water (H_2O) is formed, diluting the electrolyte solution.
- **Charging State (Reversing the Process):**
  - When an external charging voltage (like from an alternator or battery charger) is applied to the terminals, the entire chemical process is forced into reverse.
  - The Lead Sulfate ($PbSO_4$) on the plates breaks apart, reverting the positive plate back to Lead Dioxide and the negative plate back to Sponge Lead.
  - The water molecules combine with sulfate ions to recreate Sulfuric Acid, restoring the electrolyte back to its original strength and concentration.

2.1.13 Jumper Wires

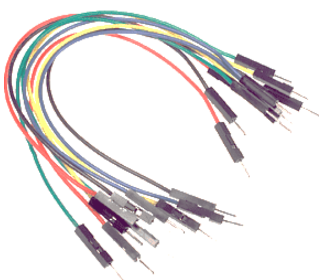


Figure 2.13: Jumper Wires

Jumper wires are low-resistance electrical conductors used to create temporary electrical connections between components on a breadboard, microcontroller, or prototyping circuit.

Their basic function relies on simple conduction:

- **Electrical Conduction:** Each wire consists of a flexible internal core made of a highly conductive metal (typically copper or aluminum) that allows electric current and data signals to pass through with minimal resistance.
- **Insulation:** The core is wrapped in a non-conductive plastic or PVC jacket. This prevents short circuits by ensuring currents do not jump between touching wires.
- **Interconnection (Male Connectors):** The ends feature solid, molded metal pins (Male terminals) designed to plug easily into female headers or breadboard tie-points, establishing a secure mechanical and electrical bridge without soldering.

Chapter 3

Methodology

3.1 Introduction

The methodology chapter outlines the strategic framework and technical procedures employed to realize the "Electricity Generation Using Gravity Battery" project. The primary objective of this research is to design and implement a sustainable energy storage solution that addresses the intermittent nature of renewable energy sources, such as solar and wind. By integrating mechanical engineering principles with electronic control systems, this methodology provides a systematic path for converting surplus electrical energy into gravitational potential energy and back into usable electricity upon demand.

Detailed Professional Explanation

The methodology of this system is engineered through a multi-disciplinary approach, focusing on three core pillars:

1. Energy Conversion and Storage Strategy

The system is designed around the principle of **Gravitational Potential Energy (GPE)**. During periods of surplus energy generated by the **Solar Panel** the system activates a **Gear Motor** to lift a heavy concrete mass to a vertical tower's highest point. This process effectively "charges" the battery by storing mechanical energy. The **Buck Converter (LM2596)** plays a critical role here by stepping down the solar voltage to a stable level required for charging the **Battery** and powering the logic circuits.

2. Intelligent Control Architecture

To ensure autonomous operation, the methodology incorporates an **Arduino-based control system**.

- **Sensing:** An **LDR (Light Dependent Resistor)** monitors ambient light to determine energy availability.
- **Logic:** The Arduino processes signals to decide when to engage the **Relay** for lifting or releasing the weight.
- **Safety:** A **Limit Switch** is integrated as a fail-safe mechanism to detect when the weight has reached its physical boundaries, preventing mechanical overstrain or structural damage.

3. Actuation and Power Generation

The discharge phase is governed by controlled descent. When the stored energy is required, the weight is released, allowing gravity to pull it down. This downward motion rotates a **Dynamo/Gear Motor**, which acts as a generator to produce electricity. The methodology utilizes a **Motor Driver (L298N)** to manage the high-current requirements of the motors while maintaining precision through the **Servo Motor** for angular adjustments.

Finally, system performance metrics specifically **Energy Conversion Efficiency** and **Power Output** are analyzed to conclude the effectiveness of the gravity-based storage solution in a grid-scale or off-grid environment.

- Precision Positioning: A Servo Motor is included for tasks requiring specific angular accuracy, such as fine-tuning the tilt of a panel.

3.1.4 Feedback and Safety Loop

To ensure mechanical integrity and operational accuracy, the system includes:

- Limit Switch: This provides physical feedback to the Arduino, acting as an "end-stop" to prevent the Gear Motor from over-rotating and causing structural damage.
- Status Indicators: LED/Output components provide immediate visual confirmation of the system's operational mode or error states.

3.2 Design of the System

The design of the automated solar control system shown in image_9289f4.png is structured into four primary functional layers: Power Management, Control Logic, Actuation, and Feedback. This architecture ensures efficient energy harvesting and precise mechanical movement.

3.2.1 Power Supply Architecture

The system utilizes a sustainable power loop designed for autonomous operation:

- Generation: A Solar Panel serves as the primary DC source.
- Regulation: A Buck Converter is integrated to step down the fluctuating solar voltage to a stable level suitable for charging and logic operations.
- Storage: A Battery is placed in parallel to provide a buffer, ensuring the Arduino and motors receive power during nocturnal periods or cloud cover.

3.2.2 Control and Sensing Logic

The intelligence of the system is centralized within the Arduino microcontroller:

- Environmental Sensing: An LDR (Light Dependent Resistor) is used as the primary input sensor to track light intensity, which informs the logic for motor positioning.
- User Interface: A Display module is connected to the Arduino to provide real-time telemetry and system status updates.

3.2.3 Actuation Mechanism

To translate logic into physical movement, the design incorporates a dual-motor strategy:

- High-Torque Drive: The Gear Motor is controlled via a Relay and Motor Driver. This setup allows the system to move heavy mechanical structures (such as a solar tracking array) with high efficiency.

- **Block Diagram**

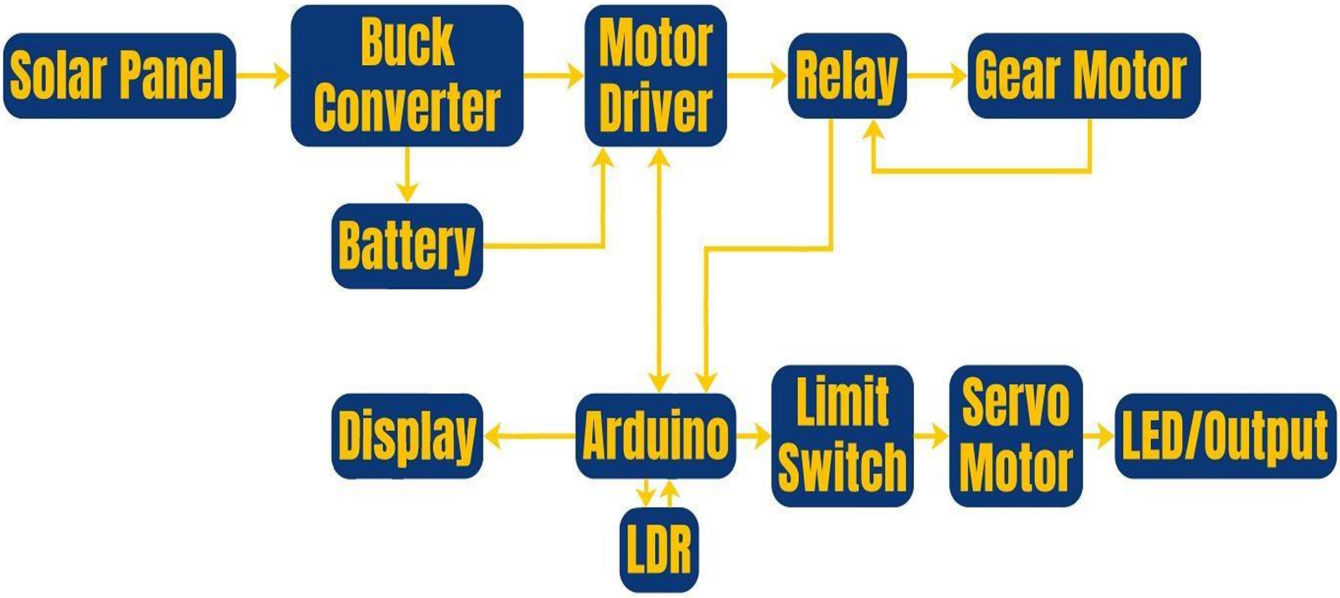


Figure 3.1: Block Diagram

Power Generation and Management

- **Solar Panel:** Acts as the primary energy harvester, converting photovoltaic energy into DC electrical power.
- **Buck Converter:** A DC-to-DC step-down converter that regulates the high voltage from the solar panel to a lower, stable voltage suitable for charging the battery and powering the electronics.
- **Battery:** Serves as the energy storage unit, ensuring the system remains operational during low-light conditions or at night.

2. Logic and Control Unit

- **Arduino:** The central microcontroller (MCU) that processes input signals from sensors and executes pre-programmed logic to control the outputs.
- **LDR (Light Dependent Resistor):** An analog sensor that detects ambient light intensity, allowing the Arduino to perform tasks like solar tracking or day/night switching.
- **Display:** Provides a visual interface to monitor real-time system data, such as battery voltage or operational status.

3. Actuation and Drive System

- **Motor Driver:** Interfaces between the Arduino and the motors, providing the necessary current and voltage to drive high-load components that the MCU cannot power directly.
- **Relay:** Acts as an electromagnetic switch to control the power flow to the Gear Motor, often used for simple ON/OFF heavy-duty operations.
- **Gear Motor:** Provides high-torque mechanical rotation for moving physical structures.
- **Servo Motor:** Used for precise angular positioning, likely for tilting the solar panel or controlling a specific mechanism.

4. Feedback and Indicators

- **Limit Switch:** A safety mechanism that sends a feedback signal to the Arduino when a moving part reaches its physical boundary, preventing mechanical overtravel or damage.
- **LED/Output:** Provides visual indicators for system alerts, power status, or successful task completion.

Summary of Operation: The system captures energy via the Solar Panel, which is conditioned by the Buck Converter to charge the Battery. The Arduino monitors environmental conditions using the LDR. Based on this data, it triggers the Motor Driver and Relay to operate the Gear Motor and Servo Motor. The Limit Switch ensures mechanical safety, while the Display and LEDs keep the user informed of the system's performance.

Circuit Diagram

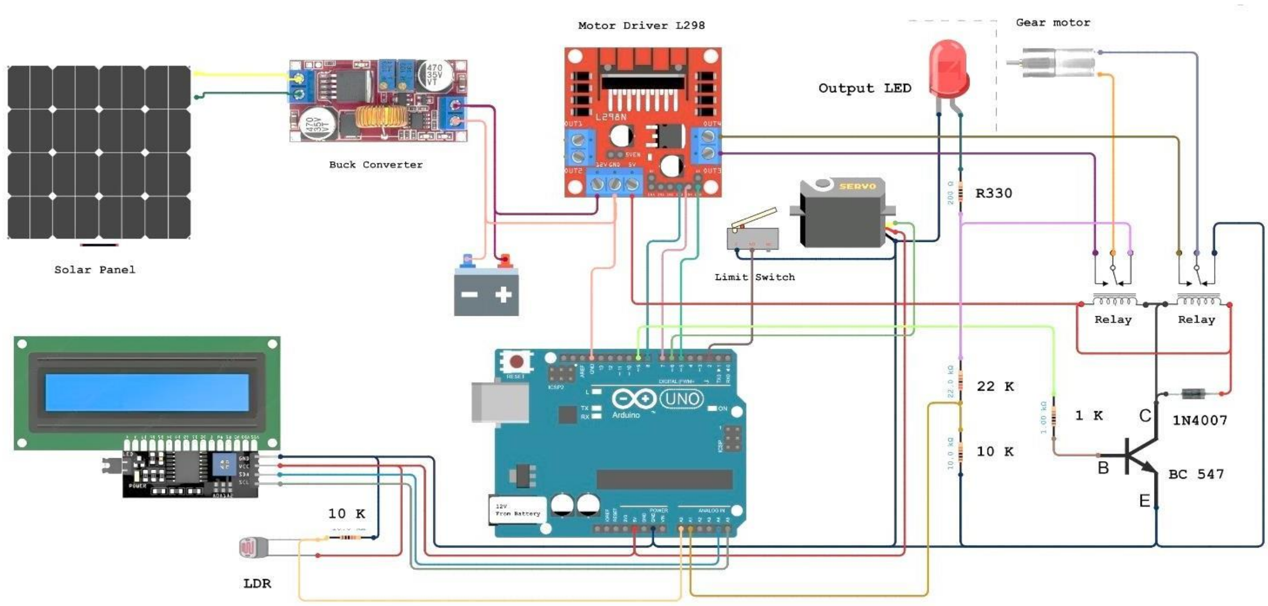


Figure 3.2: Circuit Diagram

3.3 Limitations of the System

Power and Energy Constraints

- **Solar Dependency:** The system relies on a single solar panel for charging; without a dedicated solar charge controller (MPPT or PWM), the efficiency of energy transfer to the battery via the buck converter may be suboptimal in varying light conditions.
- **Battery Capacity:** The system's runtime is strictly limited by the Amp-hour (Ah) rating of the 12V battery, which must power the Arduino, the L298N driver, a servo, and a gear motor simultaneously.
- **Voltage Regulation Risks:** The Arduino is powered directly from the battery; if the battery voltage drops significantly under motor load, it could cause the microcontroller to reset or behave erratically.

Hardware and Mechanical Limits

- **L298N Efficiency:** The L298N Motor Driver is an older, bipolar junction transistor (BJT) based driver, which is notorious for significant internal voltage drops and heat generation compared to modern MOSFET-based drivers.
- **Single-Sensor Tracking:** Using a single LDR (Light Dependent Resistor) only allows the

system to detect basic light thresholds (e.g., day/night) rather than performing active dual-axis solar tracking, which requires at least two or four sensors.

- **Mechanical Wear:** The use of a standard gear motor and servo introduces mechanical points of failure, such as gear stripping or friction, especially if the system is exposed to outdoor dust and moisture.

Control and Feedback Limitations

- **Open-Loop Issues:** While there is a limit switch shown, the gear motor appears to operate without an encoder, meaning the system cannot precisely track the exact position of its load in real-time.

Environmental Sensitivity: The LDR and exposed breadboard-style connections are sensitive to temperature fluctuations and humidity, which can lead to signal noise or corrosion over time.

3.4 Application of the System

1. Smart Solar Tracking & Energy Harvesting

The core application of this system is an **automated solar tracker**. By utilizing the LDR (Light Dependent Resistor) and a servo motor, the system can dynamically adjust the orientation of the solar panel to follow the sun's trajectory. This significantly increases the efficiency of energy collection compared to static installations. The buck converter ensures that the captured energy is regulated to a stable voltage for battery storage.

2. Off-Grid Remote Monitoring Stations

Because the system is self-powered via a battery and solar panel, it is ideal for **remote environmental monitoring**. The Arduino can be programmed to collect data from various sensors and display real-time status updates on the I2C LCD. This is particularly useful for weather stations or agricultural sensors in areas where a main power grid is unavailable.

3. Automated Residential Lighting & Security

The integration of an LDR and relays allows the system to function as an **Intelligent Lighting Controller**. It can automatically detect dusk and dawn to trigger the "Output LED" or higher-power AC loads via the relay modules. This application is commonly used for energy-efficient street lighting or automated home security systems that require a "lived-in" look while owners are away.

4. Smart Irrigation & Agricultural Automation

The gear motor and L298N motor driver can be repurposed to control **water pumps or automated feeding systems**. In an agricultural setting, the system could use the battery-stored solar power to activate irrigation valves at specific times of the day, with the LCD providing the farmer with system health and battery levels.

5. Educational Robotics and Mechatronics

The circuit serves as an excellent platform for **applied mechatronics education**. It demonstrates the integration of multiple engineering domains, including:

- **Power Electronics:** Buck conversion and battery management.
- **Control Systems:** Feedback loops between the LDR and Servo.
- **Mechanical Actuation:** Driving DC motors and servos via H-Bridge drivers.
- **Embedded Systems:** Programming the Arduino Uno to manage I2C communication and analog-to-digital signal processing.

3.5 Summary

This system is a solar-powered automated control platform based on an Arduino Uno. It uses a solar panel and 12V battery to provide off-grid power and incorporates components such as an LDR, servo motor, gear motor, L298N motor driver, relay modules, and an I2C LCD. The system can track sunlight, store energy, and control various electrical and mechanical devices.
However, the system has several limitations. Its performance depends heavily on sunlight availability and battery capacity. The use of an L298N driver results in lower efficiency and increased heat generation, while the single LDR provides only basic light detection rather than precise solar tracking. In addition, the absence of advanced feedback mechanisms limits positional accuracy, and outdoor environmental conditions may affect sensor reliability and hardware durability.

Despite these limitations, the system has many practical applications. It can be used for solar tracking, remote monitoring stations, automated lighting and security, smart irrigation, and educational robotics. Overall, the project demonstrates an effective integration of renewable energy, embedded systems, and automation technologies for both real-world and educational purpose

Chapter 4

Result Analysis

4.1 Introduction

Performance evaluation is a critical phase in any engineering project as it validates the practical feasibility of the theoretical design. After the successful assembly and integration of the mechanical and electronic components of the Gravity Battery, a series of tests were conducted to monitor its operational efficiency. This chapter focuses on analyzing how effectively the system converts electrical energy into gravitational potential energy and subsequently retrieves it as electricity.

The evaluation process primarily measures several key performance indicators (KPIs), including the charging time (the time taken to lift the mass), the stability of the output voltage during discharge, and the responsiveness of the Arduino-based control system. A significant part of this evaluation involves observing the behavior of the gear motor under load and the accuracy of the sensors in detecting the system's status.

Furthermore, this chapter discusses the results obtained from the prototype under different conditions, such as varying sunlight intensity for the solar charging unit and different weight distributions for the mass. The data collected during these trials provide essential insights into the system's overall performance, helping to identify the conversion losses and the total energy cycle efficiency. These findings are crucial for understanding the potential of scaling this prototype for real-world energy storage applications.

4.2 Hardware Used in this Circuit

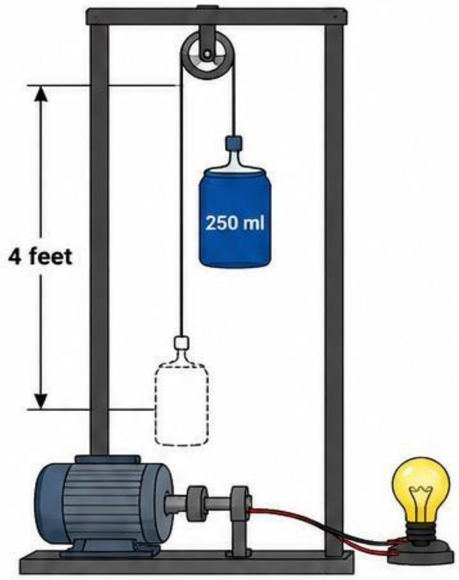
Table 4.2.1: Component List

Component	Quantity	Description
Arduino Uno	1	Microcontroller used for system control and processing
DC Motor / Generator	1	Used for lifting the weight and generating electricity during descent
Motor Driver (L298N)	1	Controls the operation of the DC motor
Servo Motor	1	Used for locking and unlocking the weight mechanism
LDR Sensor	1	Detects day and night conditions
Limit Switch	1	Detects when the weight reaches the top position
Relay Module	2	Controls the load (LED bulbs) ON/OFF
LCD Display (I2C)	1	Displays system status and voltage readings
LED Bulbs (Loads)	4	Used as loads to demonstrate generated electricity
Pulley System	1	Mechanical system for lifting and lowering the weight
Rope / String	1	Connects the pulley and weight
Weight (Mass)	1	Main component for storing gravitational energy
Wooden Frame/Board	1	Base structure for mounting the prototype
Battery (12V)	1	Provides power to the system
Buck converter	1	Steps down and stabilizes voltage from generator to a safe level for Arduino and other components
Solar Panel	1	Generates electrical energy from sunlight to power the system or assist in lifting the weight
Jumper Wires	As needed	Provides power to the system

4.3 Result and Analysis

MATHEMATICAL ANALYSIS AND POWER CALCULATION

The efficiency and power output of the **Gravity Battery** system are determined using fundamental physical and electrical equations. The calculation is divided into two parts: Potential Energy analysis and Electrical Power output.



1. POTENTIAL ENERGY CALCULATION

The energy stored in a gravity battery depends on the mass, the height it is lifted to, and the gravitational acceleration.

Formula: $E = m \times g \times h$

Given Parameters:

- **Mass (m):** 250 ml ≈ 0.25 kg
  (Assuming the density of water/material is 1 g/ml)
- **Height (h):** 4 feet ≈ 1.219 meters
  (Conversion factor: 1 ft = 0.3048 m)
- **Gravitational acceleration (g):** 9.8 m/s²

Calculation:

$$E = 0.25 \times 9.8 \times 1.219$$

$$E \approx 2.986 \text{ Joules} \approx 3 \text{ Joules}$$

2. MECHANICAL POWER OUTPUT

Power (P) is defined as the rate at which work is done or energy is transferred over time (t).

Formula: $P = \frac{E}{t}$

Given:

- Descent Time (t): 3 seconds
- Energy (E): 3 Joules

Calculation:

$$P = \frac{3}{3} = 1 \text{ Watt}$$

3 seconds

3. ELECTRICAL PARAMETERS VERIFICATION

To verify the electrical consistency of the generation, we use the electrical power formula:

Formula: $P = V \times I$

Therefore, the expected voltage output (V) can be calculated if the measured current (I) is known.

Given:

- Measured Generation Current (I): 0.2 Ampere
- Calculated Power (P): 1 Watt

Calculation:

$$V = \frac{P}{I}$$

$$V = \frac{1}{0.2} = 5 \text{ Volts}$$

SUMMARY OF RESULTS

Parameter	Symbol	Value	Unit
Mass	m	0.25	kg
Height	h	1.219	m
Gravitational Acceleration	g	9.8	m/s²
Potential Energy	E	≈ 3	Joules
Descent Time	t	3	s
Mechanical Power Output	P	1	Watt
Measured Current	I	0.2	A
Expected Voltage Output	V	5	Volts

KEY TAKEAWAYS

- The system stores potential energy by lifting a mass to a height.
- This potential energy is converted to mechanical power during descent.
- The mechanical power drives a generator to produce electrical energy.
- With the given parameters, the system produces approximately 5 Volts at 0.2 Ampere.

Chapter 5

Conclusion

5.1 Device prototype

The prototype is mounted on a sturdy wooden board, where the main structure of the gravity battery consists of a vertical frame, a pulley system, and a heavy mass. Energy is stored by lifting the mass to a higher position, and when it is lowered, the stored energy is converted into electrical energy.

A DC motor/generator is integrated into the system to convert the kinetic energy of the descending mass into electrical energy. The generated electricity is demonstrated using several LED bulbs as loads.

For the control system, an Arduino Uno is used to manage the overall operation of the system. Additionally, a relay module is incorporated to control the load effectively.

All components are securely and neatly connected, with clear labeling provided for each part to ensure that the prototype is easy to understand and operate

Figure 5.1: System Complete Setup

5.2 Working principle

The proposed system operates as a self-sustaining solar-powered automation platform that combines renewable energy harvesting, battery storage, sensor-based monitoring, and electromechanical control. The entire operation is coordinated by the Arduino Uno, which continuously reads sensor inputs, processes the data according to the programmed logic, and drives the connected actuators and indicators.

1. Solar Energy Collection and Battery Charging

The system begins with a photovoltaic solar panel, which converts sunlight into direct current (DC) electrical energy. Because the voltage generated by the panel varies with solar intensity and temperature, the output is first routed through a buck converter. This converter regulates the panel voltage to a safe and stable level suitable for charging the 12 V battery.

The battery serves as the main energy reservoir of the system. It stores the harvested energy and provides a dependable power source even when sunlight is unavailable, such as during cloudy conditions or at night. By using a rechargeable battery, the system can continue to operate autonomously without requiring an external utility power supply.

2. Power Distribution to the Control Circuit

The stored battery energy is distributed to all circuit sections. The Arduino Uno receives power and acts as the central processing unit of the system. Other components, including the L298N motor driver, servo motor, relays, LCD module, and sensing circuits, are also powered from the same energy source.

This arrangement ensures that all subsystems remain synchronized and can function from a single renewable energy source, making the design highly suitable for off-grid applications.

3. Light Detection Using the LDR Sensor

A Light Dependent Resistor (LDR) is used to detect ambient light intensity. The resistance of the LDR decreases when exposed to strong light and increases under low-light conditions. Together with a 10 kΩ resistor, it forms a voltage divider that produces an analog voltage proportional to the surrounding brightness.

The Arduino reads this analog signal through one of its analog input pins and converts it into a digital value. Based on this value, the controller determines whether sufficient sunlight is available and decides how the rest of the system should respond.

4. Solar Panel Positioning with the Servo Motor

The servo motor is responsible for adjusting the angular position of the solar panel or related mechanical assembly. When the Arduino detects favorable light conditions, it sends a pulse-width modulation (PWM) signal to the servo. The servo then rotates to a predetermined angle to orient the panel toward the strongest light source.

This automatic alignment improves the amount of solar radiation captured by the panel and enhances overall charging performance compared with a fixed installation.

5. Mechanical Motion Control with Gear Motor and L298N Driver

For applications requiring greater torque and extended movement, a DC gear motor is used. Since the Arduino cannot supply sufficient current directly, the motor is controlled through an L298N dual H-bridge driver.

The Arduino sends logic signals to the input pins of the L298N, and the driver switches battery power to the gear motor in the desired direction. This enables the system to perform tasks such as rotating a mechanical structure, lifting a load, or driving a linear mechanism.

Although the L298N introduces some voltage loss, it provides reliable motor control and electrical isolation between the microcontroller and the higher-current load.

6. Position Protection with the Limit Switch

A limit switch is incorporated to define the safe travel boundary of the moving mechanism. When the motor-driven assembly reaches its mechanical endpoint, the switch changes state and sends a signal to the Arduino.

The controller immediately stops or reverses the motor to prevent overtravel, reducing the risk of structural damage and extending the service life of the mechanical components.

7. Relay Switching and Transistor Interface

Two relay modules are included to control higher-power loads that cannot be driven directly by the Arduino. A BC547 transistor acts as an intermediate switching stage, allowing the low-current Arduino output to energize the relay coil safely.

A 1N4007 diode is connected across the relay coil to suppress reverse voltage generated when the coil is switched off. This flyback protection safeguards the transistor and microcontroller from voltage spikes.

Depending on the programmed conditions, the relays can activate devices such as pumps, lights, chargers, or other electrical equipment.

8. LED Status Indication

An output LED is connected through a current-limiting resistor (330 Ω) to provide a visual indication of system status. The LED may illuminate when charging is active, when a relay is energized, or when the system enters a specific operating mode.

This simple indicator allows the user to verify system activity at a glance.

9. Real-Time Information Display on the I2C LCD

A 16×2 LCD equipped with an I2C interface displays important operating parameters. Through only two communication lines (SDA and SCL), the Arduino transmits data such as:

- Light intensity level
- Battery charging status
- Motor position
- Relay condition
- Fault or warning messages

The display offers a convenient user interface for observing system behavior in real time.

10. Control Logic and Decision Making

The Arduino executes a continuous monitoring and control loop. During each cycle, it:

1. Reads the LDR value.
2. Checks the state of the limit switch.
3. Determines battery and charging conditions.
4. Positions the servo motor.
5. Starts or stops the gear motor through the L298N driver.
6. Activates relays when required.
7. Updates the LCD and LED indicators.

This closed-loop process allows the system to respond automatically to environmental changes and operational constraints.

11. Operation During Day and Night

During daylight, the LDR detects strong illumination. The Arduino positions the solar panel for effective charging and may enable selected loads if adequate energy is available.

As light intensity decreases, the controller can park the mechanism, disable nonessential outputs, and conserve stored battery energy. This intelligent energy management ensures stable operation under changing conditions.

12. Overall Functional Behavior

In practical operation, the system performs the following sequence:

- Captures solar energy through the photovoltaic panel.
- Regulates the charging voltage with the buck converter.
- Stores energy in the 12 V battery.
- Monitors ambient light using the LDR.
- Adjusts panel orientation with the servo motor.
- Drives mechanical movement using the gear motor and L298N.

- Protects travel limits with the limit switch.
- Controls external devices via relays.
- Displays real-time information on the LCD.
- Indicates operating status through the LED.

Conclusion

The working principle of this system is based on the integration of solar energy conversion, embedded control, and automated actuation. By combining sensing, decision-making, and power switching within a single Arduino-based platform, the system is capable of operating autonomously with minimal human intervention. This design is well suited for solar tracking, agricultural automation, remote monitoring, and educational applications where reliable off-grid control is required.

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23. **Park, S., & Kim, J. (2023).** "Design and control of a regenerative braking system integrated with gravity energy storage for rail transport." *IEEE Access, Vol. 11, pp. 24350-24361.*
    A. ***Source/Link:*** *IEEE Xplore Open Access (ieeexplore.ieee.org)*
24. **Glavan, M., & Kumar, R. (2021).** "Environmental Life Cycle Assessment (LCA) of Gravity Batteries versus Lithium-Ion Batteries." *Journal of Environmental Management, Vol. 295, pp. 113110.*
    A. ***Source/Link:*** *Elsevier ScienceDirect (sciencedirect.com)*
25. **Patel, A., & Sharma, S. (2024).** "Prototyping and Experimental Verification of a Low-Cost Laboratory-Scale Gravity Energy Storage System." *International Journal of Power Electronics, Vol. 19, No. 3, pp. 289-304.*
    A. ***Source/Link:*** *Inderscience Publishers (inderscience.com)*

The information, technical data, images, and conceptual frameworks included in this project have been compiled using a variety of reliable digital resources. I acknowledge and credit the following platforms for providing the valuable data that supported the development and visual content of this project book:

1. **Wikipedia (The Free Encyclopedia)**
    - *Topic:* Photovoltaics and Solar Power.
    - *Usage:* Used for technical definitions, historical background, and scientific principles of the Photovoltaic Effect.
    - *Source:* https://en.wikipedia.org/wiki/Photovoltaics

2. **Google Search & Scholar**
    - *Usage:* Used for cross-referencing facts, sourcing diverse articles, and gathering general industrial data related to solar energy systems.
    - *Source:* https://www.google.com
3. **YouTube (Educational Channels)**
    - *Usage:* Used for visual understanding of solar panel internal structures, animations of electron flow, and simplified explanations of the inverter process.
    - *Reference:* Various engineering and educational creators (e.g., Engineering Explained, Veritasium).
4. **OpenAI (ChatGPT)**
    - *Usage:* Used for content structuring, summarizing complex technical jargon into simplified language, and assistance in drafting original descriptions to ensure clarity.
    - *Interaction:* AI-assisted research and text generation.
5. **Image Sources**
    - *Usage:* Diagrams, flowcharts, and illustrative photos were sourced and adapted from Creative Commons and public domain searches via Google Images and Wikipedia Commons.

Appendix

The Code Used in Arduino Uno

```
#include <Servo.h>
#include <Wire.h>
#include <LiquidCrystal_I2C.h>

// LCD setup
LiquidCrystal_I2C lcd(0x27, 16, 2);

// Servo object
Servo lockServo;

// Pin definitions
#define IN1 7
#define IN2 8
#define ENA 5
#define LDR A0
#define TOP_LIMIT 2
#define SERVO_PIN 6
#define VOLT_PIN A1
#define RELAY_PIN 9

// Variables
int sLock = 20;
int sUnlock = 90;
int dayThres = 300;
int mSpeed = 150;

// System states
enum State { LIFTING, LOCKED, GENERATING };
State sysState = LIFTING;

// ---------------------- SETUP ----------------------
void setup() {
  pinMode(IN1, OUTPUT);
  pinMode(IN2, OUTPUT);
```

```
  pinMode(ENA, OUTPUT);
  pinMode(RELAY_PIN, OUTPUT);
  pinMode(TOP_LIMIT, INPUT_PULLUP);

  Wire.begin();
  lcd.init();
  lcd.backlight();

  // Intro display
  showIntro(F(" SONARGAON UNI "), F("   EEE PROJECT    "), 3000);
  showIntro(F(" GRAVITY BATTERY "), F("      SYSTEM        "), 2500);

  lockServo.attach(SERVO_PIN);
  lockServo.write(sUnlock);

  digitalWrite(RELAY_PIN, LOW);
}

// ---------------------- LOOP ----------------------
void loop() {
  int light = analogRead(LDR);
  bool isDay = (light > dayThres);
  bool topReached = (digitalRead(TOP_LIMIT) == LOW);

  switch (sysState) {

    // --------- LIFTING ---------
    case LIFTING:
      digitalWrite(RELAY_PIN, LOW);

      if (isDay) {
        if (!topReached) {
          liftMotor();
          updateLCD(F("Lifting..."), F("Motor Running"));
        } else {
          stopMotor();
          lockServo.write(sLock);
          delay(1000);

          sysState = LOCKED;
```

```
        lcd.clear();
      }
    } else {
      stopMotor();
      updateLCD(F("Waiting Day"), F("Now: Night"));
    }
    break;

  // -------- LOCKED --------
  case LOCKED:
    stopMotor();
    digitalWrite(RELAY_PIN, LOW);

    updateLCD(F("Status: Locked"), F("Fully Charged"));

    if (!isDay) {
      lockServo.write(sUnlock);
      delay(500);

      sysState = GENERATING;
      lcd.clear();
    }
    break;

  // -------- GENERATING --------
  case GENERATING:
    stopMotor();
    digitalWrite(RELAY_PIN, HIGH);

    unsigned long startTime = millis();

    while (millis() - startTime < 5000) {
      float volt = analogRead(VOLT_PIN) * (5.0 / 1023.0) * 3.136;

      lcd.setCursor(0, 0);
      lcd.print(F("Generating..."));

      lcd.setCursor(0, 1);
      lcd.print(F("Volt: "));
      lcd.print(volt, 1);
```

```
      lcd.print(F(" V     "));

      delay(200);
    }

    digitalWrite(RELAY_PIN, LOW);
    lcd.clear();

    // Wait until day comes again
    while (analogRead(LDR) <= dayThres) {
      updateLCD(F("Waiting Day"), F("Now: Night"));
      delay(500);
    }

    sysState = LIFTING;
    lcd.clear();
    break;
  }

  delay(100);
}

// ---------------------- FUNCTIONS ----------------------

// Motor lift function
void liftMotor() {
  digitalWrite(IN1, HIGH);
  digitalWrite(IN2, LOW);
  analogWrite(ENA, mSpeed);
}

// Motor stop function
void stopMotor() {
  digitalWrite(IN1, LOW);
  digitalWrite(IN2, LOW);
  analogWrite(ENA, 0);
}

// LCD update function
void updateLCD(const __FlashStringHelper* line1, const __FlashStringHelper* line2) {
```

```
  lcd.setCursor(0, 0);
  lcd.print(line1);

  lcd.setCursor(0, 1);
  lcd.print(line2);
}

// Intro display function
void showIntro(const __FlashStringHelper* line1, const __FlashStringHelper* line2, int duration) {
  lcd.clear();
  updateLCD(line1, line2);
  delay(duration);
}
```