Design and Fabrication of a Solar Energy-Based Water Pumping System

A Thesis

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May, 2026

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A report submitted to the Department of Mechanical, Sonargaon University of Bangladesh, in partial fulfilment of the requirements for the award of the degree of Bachelor of Science in mechanical engineering**.**

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Approval

This is to certify that the project work entitled **"Design and Fabrication of a Solar Energy-Based Water Pumping System"** has been carried out by Mithun Das Pritom (ID: ME2203028236), Md. Abu Raihan (ID: ME2203028218), Md. Shah Nawaz Perez (ID: ME2203028366), and Mst. Sarmin Sapla (ID: ME2203028273). We hereby declare that the work presented in this project is original and has not been submitted elsewhere for the award of any degree or certificate. This project was completed under the supervision of Md. Navid Inan, Lecturer, Department of Mechanical Engineering, Sonargaon University.

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DECLARATION

We hereby solemnly and sincerely declare that the work presented in this project report has been carried out entirely by us in the Department of Mechanical Engineering and is the result of our own effort, research, and study. We further declare that this work has not been previously submitted, either in whole or in part, to any university, institution, or organization for the award of any degree, diploma, or certificate.

We also confirm that all sources of information, ideas, data, and materials used in this report have been properly acknowledged and cited wherever applicable, and that no part of this report infringes upon any existing copyright, intellectual property rights, or published work of others.

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ACKNOWLEDGEMENT

In the name of Almighty Allah, the Most Gracious and Most Merciful, we begin this thesis work.

First and foremost, we express our deepest gratitude to Almighty Allah for His infinite mercy, blessings, and guidance, without which the completion of this thesis would not have been possible. His divine support has always guided us through every stage of this academic journey.

This thesis has been conducted under the supervision of **Md. Navid Inan**, Lecturer, Department of Mechanical Engineering, Sonargaon University. We want to express our sincere appreciation and profound respect to our honorable supervisor for his continuous guidance, valuable suggestions, constructive criticism, and constant encouragement throughout this research work. His insightful advice, academic expertise, and patient supervision played a crucial role in shaping this thesis into its final form. We are truly grateful for his dedicated time, motivation, and unwavering support, which helped us overcome numerous challenges during the research process.

We are also highly grateful to **Md. Mostofa Hossain**, Head of the Department of Mechanical Engineering, Sonargaon University, for his kind cooperation, encouragement, and support during the entire course of our study. His leadership and continuous motivation have been a great source of inspiration for us.

Furthermore, we would like to extend our heartfelt gratitude to all the respected faculty members of the Department of Mechanical Engineering, Sonargaon University, for their valuable teachings, guidance, and support throughout our academic journey. Their knowledge and encouragement have greatly contributed to our learning and development as engineering students.

We also acknowledge the support and cooperation of our classmates and friends, who have been a constant source of motivation, encouragement, and assistance during the completion of this thesis work. Their companionship and helpful discussions made this journey more meaningful and enjoyable.

Finally, we would like to express our gratitude to our parents and family members for their endless love, prayers, sacrifices, and moral support. Their unwavering encouragement and belief in us have been the greatest strength behind our success.

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ABSTRACT

This project presents the design, development, and implementation of a solar-powered automatic water-pumping system intended primarily for rural, remote, and off-grid applications where access to reliable electricity is limited or unavailable. The main objective of this system is to provide a sustainable, energy-efficient, and cost-effective solution for water supply using renewable solar energy. The proposed system integrates several key components, including a photovoltaic (PV) solar panel for energy harvesting, a rechargeable battery storage unit for energy backup, a charge controller for efficient power management, and a voltage regulation circuit to ensure stable system operation. In addition, an automatic control mechanism is implemented using a float switch and relay module, which enables the system to start and stop the water pump automatically based on the water level in the storage tank. To enhance the safety and durability of the system, a low-voltage cutoff (LVC) module is incorporated to protect the battery from deep discharge conditions, thereby extending battery life and improving overall system reliability. The entire system is designed to operate on direct current (DC) power, eliminating the need for grid electricity as well as reducing dependence on conventional fuel-based pumping systems. The performance of the system has been evaluated through experimental testing under practical conditions. The results indicate that the system operates reliably, efficiently harvests solar energy, and successfully performs automatic water tank filling without manual intervention. The use of renewable solar energy not only reduces operational costs but also minimizes environmental impact by eliminating carbon emissions associated with fossil fuel-based pumps. Overall, the proposed design is simple, scalable, and economically feasible. It can be effectively implemented for domestic water supply, small-scale irrigation systems, and other agricultural applications, especially in rural and developing regions. The system offers a sustainable alternative to conventional water pumping methods and contributes to the promotion of green energy technologies.

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CHAPTER-1

INTRODUCTION

1.1 Introduction

Energy is one of the most essential requirements for modern civilization. Industrial development, agriculture, transportation, communication, and domestic activities all depend heavily on electrical energy. Conventional energy resources such as coal, oil, and natural gas are limited and continuously decreasing due to excessive consumption. Moreover, fossil fuel-based energy systems produce environmental pollution and greenhouse gas emissions.

As a result, researchers and engineers around the world are focusing on renewable energy technologies. Solar energy is considered one of the most promising renewable energy resources because it is abundant, free, and environmentally friendly. Solar energy can be converted directly into electrical energy using photovoltaic technology.

Water pumping is one of the major applications of solar photovoltaic systems. Water is essential for agriculture, irrigation, domestic supply, livestock farming, and industrial activities. In many rural regions, reliable electricity supply is unavailable, making water pumping difficult and expensive. Diesel-powered pumps are commonly used in such areas, but they increase fuel cost and environmental pollution.

Solar-powered water pumping systems provide a sustainable and economical solution. These systems use solar energy to operate water pumps without requiring grid electricity or fuel.

The present project focuses on the design and fabrication of a low-cost automatic solar water pumping system using a 12V 20W solar panel, 12V battery, relay module, float switch, and DC water pump.

1.2 Background of the Study

Bangladesh receives sufficient solar radiation throughout the year. The average solar radiation in Bangladesh ranges from 4 to 6.5 $kWh/m^2/day$, making solar energy highly suitable for renewable energy applications [1]. Rural regions of Bangladesh face frequent electricity shortages, especially in agricultural areas.

Farmers often use diesel pumps for irrigation, which increases operating costs. Solar-powered pumping systems can significantly reduce fuel dependency and improve irrigation efficiency.

The advancement of photovoltaic technology and decreasing solar panel cost have made solar pumping systems more affordable and practical for small-scale applications.

1.3 Problem Statement

The major problems associated with conventional water pumping systems are:

- Dependence on grid electricity
- High diesel fuel cost
- Environmental pollution
- High maintenance cost
- Noise pollution
- Limited access to electricity in remote areas

Therefore, an alternative renewable energy-based pumping system is required.

1.4 Objectives of the Project

Main Objective

To design and fabricate a solar energy-based automatic water pumping system.

Specific Objectives

- To generate electrical energy using a photovoltaic solar panel
- To store energy using a rechargeable battery
- To analyze system performance and efficiency

1.5 Scope of the Project

The scope of the project includes:

- Solar energy harvesting
- Battery charging and storage
- Water pumping using a DC motor

- Automatic control operation
- Hydraulic and electrical analysis
- Experimental testing and evaluation

1.6 Importance of the Project

The project is important because:

- It promotes renewable energy usage
- It reduces electricity consumption
- It is environmentally friendly
- It is suitable for rural and remote areas
- It reduces operational cost
- It provides sustainable irrigation solutions

CHAPTER-2

LITERATURE REVIEW

2.1 Introduction

Renewable energy has become a central focus of modern engineering research due to the increasing global demand for energy, depletion of fossil fuel reserves, and rising environmental concerns. Conventional energy sources such as coal, oil, and natural gas are not sustainable for long-term use because they contribute significantly to greenhouse gas emissions and global warming. In addition, the continuous increase in fuel prices has made conventional energy systems economically challenging, especially for developing countries [3], [29].

To address these issues, researchers have shifted their attention toward renewable energy technologies such as solar, wind, hydro, biomass, and geothermal energy. Among these, solar energy has emerged as one of the most promising sources due to its abundance, cleanliness, and wide availability across the globe. Photovoltaic (PV) systems directly convert sunlight into electrical energy using semiconductor materials, making them highly suitable for decentralized energy production [1], [13].

In countries like Bangladesh, where solar radiation is available throughout the year, solar energy plays a crucial role in rural electrification and agricultural development. Solar-based applications such as lighting systems, battery charging stations, irrigation pumps, and water supply systems are increasingly being implemented in off-grid areas [12], [27]. Among these applications, solar-powered water pumping systems are particularly important because water is essential for agriculture, livestock, and domestic use.

2.2 Photovoltaic System Development

Photovoltaic technology has experienced rapid growth over the past few decades. A PV system operates based on the photovoltaic effect, where sunlight falling on a semiconductor material generates electron-hole pairs, producing direct current (DC) electricity. This principle allows direct conversion of solar radiation into usable electrical energy without any mechanical movement [1], [11].

PV systems are widely used in off-grid and remote applications due to their reliability, long lifespan, and low maintenance requirements. Unlike conventional generators, PV systems do not contain rotating parts, which reduces mechanical wear and increases system durability [14]. According to Kalogirou, PV systems are highly suitable for decentralized power generation and rural electrification due to their simplicity and environmental benefits [1].

The performance of PV systems depends on several factors such as solar irradiance, ambient temperature, dust accumulation, shading effects, and panel orientation [8], [26]. Solar irradiance directly affects current generation, while temperature has an inverse effect on voltage output. Studies show that PV efficiency decreases with increasing temperature due to semiconductor property changes [5], [6].

To ensure stable operation, PV systems are often integrated with batteries and charge controllers. These components help store excess energy and regulate voltage levels to prevent overcharging and deep discharge conditions [8], [13]. Recent advancements in solar panel technology, such as monocrystalline and polycrystalline silicon cells, have significantly improved conversion efficiency and reduced cost [13], [28].

2.3 Solar Energy in Water Pumping Systems

Solar-powered water pumping systems have become an important application of renewable energy in agricultural and rural sectors. Traditionally, water pumps are operated using diesel engines or grid electricity. However, these systems are associated with high operational costs, fuel dependency, and environmental pollution [2], [16].

A solar water pumping system consists of photovoltaic panels, a charge controller, an electric motor, a pump, and a water storage system. The system converts solar energy into electrical energy, which is then used to drive a motor connected to a pump that lifts water from underground sources or surface reservoirs [7], [10].

The energy conversion process can be expressed as:

Solar Energy → Electrical Energy → Mechanical Energy → Hydraulic Energy [26]

From a fluid mechanics perspective, pump performance depends on parameters such as head, discharge, pipe losses, and pump efficiency [2], [7]. Streeter and Wylie explain that hydraulic machines play a critical role in converting mechanical energy into fluid energy for water transport systems [9].

Solar irrigation systems are highly efficient because water demand is usually highest during sunny periods, when solar energy availability is also maximum. This natural synchronization makes solar pumping systems highly suitable for agricultural applications [27], [29].

Despite these advantages, solar water pumping systems face challenges such as high initial installation cost, weather dependency, and reduced efficiency during cloudy conditions [1], [12]. However, continuous technological improvements are gradually reducing these limitations.

2.4 DC Pumping Systems

DC motor-based pumping systems are widely used in photovoltaic applications because they operate directly on DC power without requiring an inverter. This reduces system complexity and energy conversion losses [3], [23].

DC pumps are commonly used in small-scale irrigation, livestock water supply, and rural household applications. These systems are simple, cost-effective, and easy to maintain. The speed of a DC motor depends on input voltage, which allows direct control of pump performance based on solar irradiance conditions [23].

According to Rashid, DC motor systems are highly efficient for low-power applications due to their simple control characteristics and direct compatibility with battery storage systems [4]. However, DC pumps generally have lower efficiency and limited capacity compared to industrial AC pumps [24].

Despite these limitations, DC pumping systems remain widely adopted in rural areas due to their affordability and ease of installation [21].

2.5 Automatic Control Systems

Automatic control systems play a vital role in improving the efficiency and safety of solar-powered pumping systems. These systems reduce human intervention and ensure proper operation under varying environmental conditions [21].

One of the most commonly used control methods is the float switch mechanism. Float switches detect water level changes and automatically control pump operation. When the tank is full, the pump is turned off, and when the water level drops, the pump is activated [4].

Relay modules are also widely used to control high-power electrical devices using low-power signals. In solar pumping systems, relays are used in combination with sensors and float switches to automate pump operation [17].

The advantages of automatic control systems include:

- Prevention of water overflow
- Protection against dry running of pumps
- Energy saving
- Improved system reliability
- Reduced manual intervention

According to El-Sharkawi, automation improves operational safety and system efficiency in electrical energy systems [21].

2.6 Effect of Temperature on Solar Panels

Temperature has a significant impact on the performance of photovoltaic systems. Although solar panels require sunlight to generate electricity, excessive temperature reduces their efficiency [5].

As temperature increases, the output voltage of a PV panel decreases, leading to reduced power output. Most silicon-based solar panels have a temperature coefficient of approximately -0.4% to -0.5% per °C above standard test conditions (25°C) [6], [28].

Frank White explains that environmental factors such as heat and fluid flow conditions significantly affect system performance in engineering applications [7]. In tropical regions like Bangladesh, high ambient temperature often reduces solar panel efficiency [12].

Factors contributing to temperature rise include:

- High solar irradiance
- Poor ventilation
- Dust accumulation
- Low wind speed

Various cooling techniques such as air cooling, water cooling, and heat sink integration have been proposed to improve performance [10], [13].

Despite temperature-related losses, PV systems remain reliable and efficient energy sources for rural applications [1].

2.7 Summary of Literature Review

The reviewed literature clearly shows that solar-powered water pumping systems are a sustainable and effective solution for rural water supply and agricultural applications. Photovoltaic systems provide clean, renewable, and environmentally friendly energy that can replace conventional diesel-based pumping systems [1], [29].

DC pumping systems are particularly suitable for small-scale applications due to their simplicity and direct compatibility with solar systems [3], [23]. Automatic control systems using float switches and relays significantly improve system safety, reliability, and efficiency [4], [17].

However, environmental factors such as temperature and solar irradiance strongly influence system performance [5], [6]. Despite these challenges, continuous technological improvements have made solar pumping systems more efficient and cost-effective.

Overall, the literature indicates a strong need for simple, low-cost, and efficient solar water pumping systems suitable for rural applications. This project aims to address this need by integrating photovoltaic power generation, DC pumping technology, and automatic control systems into a single compact solution.

CHAPTER-3

System Design and Methodology

3.1 Mechanical Engineering Perspective

From a mechanical engineering viewpoint, solar-powered water pumping systems involve the combined application of thermodynamics, fluid mechanics, hydraulic machines, renewable energy engineering, and energy conversion systems. The developed system converts solar energy into electrical energy and finally into hydraulic energy for transporting water.

Mechanical engineering analysis in this project mainly focuses on:

- Photovoltaic Effect
- Battery Energy Storage
- Water Pumping Theory
- Pipe Flow Theory
- Relay Module Theory
- Float Switch Operation

The project integrates renewable energy systems with fluid transport mechanisms and hydraulic engineering principles.

The average solar irradiance under standard test conditions is:

1000 W/m^2

3.2 Photovoltaic Effect

The photovoltaic effect is the process by which solar cells convert sunlight into electrical energy.

When photons strike semiconductor materials, electron-hole pairs are generated, producing an electric current.

The output power of a solar panel depends on:

- Sunlight intensity
- Temperature
- Panel orientation

- Surface cleanliness
- Load condition

3.3 Battery Energy Storage

A rechargeable battery stores electrical energy generated by the solar panel.

Battery energy can be calculated using:

$E = V \times Ah$

Where:

E=Energy in watt-hour
V=Battery voltage
Ah = Battery capacity

For the 12V 9Ah battery:

$E = 12 \times 9$

$E = 108\ Wh$

Thus, the battery can theoretically store 108 watt-hours of electrical energy.

3.4 Water Pumping Theory

Water pumps convert electrical energy into mechanical energy to transfer water from one location to another.

The hydraulic power equation is:

$Ph = \rho gQH$

Where:

Ph = Hydraulic power
ρ = Density of water
Q = Flow rate
H = Pump head

3.5 Pipe Flow Theory

The diameter of the pipe significantly affects water velocity and friction losses.

The project uses a 10 mm diameter pipe.

Radius:

$r = 5 \text{ mm} = 0.005 \text{ m}$

Pipe area:

$A = \pi r^2$

$A = 3.1416 \times (0.005)^2$

$A = 7.85 \times 10^{-5} \text{ m}^2$

3.6 Relay Module Theory

A relay is an electrically operated switch used to control high-current loads using low-power control signals.

The relay module used in this project controls the operation of the water pump automatically.

3.7 Float Switch Operation

A float switch is used to monitor the water level.

When the water level reaches the upper limit:

- Float switch disconnects the relay
- Pump stops automatically

When the water level falls below the lower limit:

- Relay activates
- Pump starts automatically

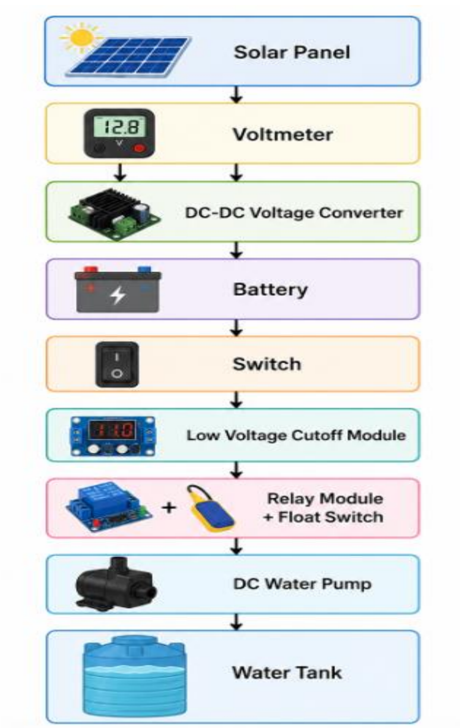
3.8 System Overview

The developed solar water pumping system consists of the following major components:

- 12V 20W solar panel

- Digital voltmeter
- DC-DC voltage converter
- 12V 9Ah battery
- Switch
- Low-voltage cutoff module
- Relay module
- Float switch
- 12V DC water pump

3.9 System Block Diagram



System Block Diagram

3.10 Design Methodology

The project was completed using the following methodology:

1. Component selection
2. Circuit design
3. Hardware assembly
4. Wiring and soldering

5. Pump installation
6. Experimental testing
7. Performance analysis

3.11 Circuit Operation

The solar panel converts sunlight into electrical energy.

The generated voltage is monitored using the voltmeter and regulated using the DC-DC converter before charging the battery.

The battery supplies power to the load.

The low-voltage cutoff module disconnects the load if the battery voltage falls below a safe operating limit.

The float switch and relay module automatically control the operation of the water pump.

3.12 Solar Panel

Polycrystalline solar panel

Specifications:

Parameter	Value
Rated Voltage	12V
Rated Power	20W
Maximum Current	1.67A

Solar panel current calculation:

I = P/V

I = 20/12

I = 1.67A

3.13 DC-DC Voltage Converter

DC-DC Voltage Converter

The DC-DC converter stabilizes the charging voltage and improves charging efficiency.

Functions:

- Voltage regulation
- Stable battery charging
- Improved efficiency
- Overvoltage protection

3.14 Battery

Lead-acid Battery

Specifications:

Parameter	Value
Voltage	12V
Capacity	9Ah

Battery backup calculation:

Assuming pump current = 1.5A

Backup time:

t = Ah/I

t = 9/1.5

t = 6 hours

Therefore, the battery can theoretically operate the pump for approximately 6 hours.

3.15 Voltmeter

DC Voltmeter

The voltmeter measures the output voltage of the solar panel and battery.

Advantages:

- Real-time voltage monitoring
- Easy troubleshooting
- Battery condition monitoring

3.16 Switch


Switch

The switch is used to manually turn the system ON and OFF.

3.17 Low Voltage Cutoff Module


Low Voltage Cutoff Module

The low-voltage cutoff module protects the battery from deep discharge conditions.

Functions:

- Battery protection
- Automatic load disconnection
- Improved battery life

3.18 Relay Module

Relay Module

The relay module controls the pump automatically according to float switch signals.

3.19 Float Switch

Float Switch

The float switch monitors the water level inside the tank.

3.20 Water Pump

DC Water Pump

Specifications:

Parameter	**Value**
Voltage	12V

Parameter	**Value**
Flow Rate	600 L/h
Pipe Diameter	10 mm

Flow rate conversion:

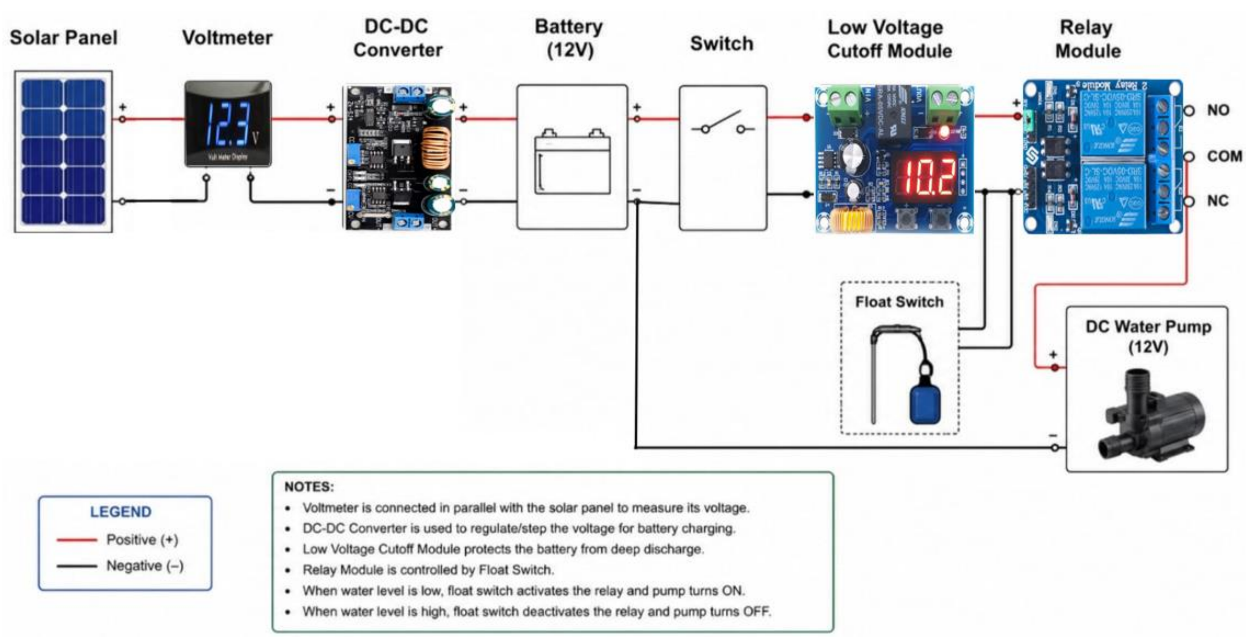
600 L/h = 10 L/min

$Q = 600/(1000 \times 3600)$

$Q = 0.000167\ m^3/s$

3.21 Circuit Diagram

12V Solar Panel → Voltmeter → DC-DC Converter → Battery → Switch → Low Voltage Cutoff Module → Relay Module → Float Switch → DC Water Pump



Circuit Diagram

3.22 Working Principle

The solar panel converts sunlight into electrical energy.

The DC-DC converter regulates the charging voltage.

The battery stores energy and supplies power to the load.

When the switch is ON, power flows through the low-voltage cutoff module.

If battery voltage remains above the preset value, the relay activates.

The float switch detects the water level.

If the water level is low:

- Relay turns ON
- Pump starts

If the water tank becomes full:

- Float switch disconnects relay
- Pump stops automatically

CHAPTER-4

ENGINEERING CALCULATIONS

4.1 Solar Power Calculation

Power equation:

$P = VI$

For the solar panel:

$P = 12 \times 1.67$

$P = 20.04W$

Thus, the panel generates approximately 20W.

4.2 Daily Energy Generation

Assuming effective sunlight duration = 5 hours/day

Daily energy:

$E = Pt$

$E = 20 \times 5$

$E = 100Wh/day$

4.3 Battery Charging Time

Battery energy:

108Wh

Charging power:

20W

Charging time:

$t = E/P$

$t = 108/20$

$t = 5.4$ hours

Therefore, the battery requires approximately 5.4 hours for full charging under ideal conditions.

4.4 Pipe Area Calculation

Pipe diameter = 10 mm

Radius:

$r = 0.005m$

Area:

$A = \pi r^2$

$A = 3.1416 \times (0.005)^2$

$A = 7.85 \times 10^{-5}\ m^2$

4.5 Water Velocity Calculation

Flow rate:

$Q = 0.000167 m^3/s$

Velocity:

$v = Q/A$

$v = 0.000167/(7.85 \times 10^{-5})$

$v = 2$

Water velocity is an important hydraulic parameter in fluid mechanics. It determines the movement of water through the pipeline and affects friction loss, pressure distribution, and pump performance.

According to the continuity equation of fluid mechanics:

$Q = AV$

Where:

Q = Volumetric flow rate
A = Pipe cross-sectional area
V = Velocity of fluid

The continuity equation states that the volumetric flow rate remains constant throughout the pipe under steady-state incompressible flow conditions.

In this project, the pipe diameter was 10 mm, and the pump discharge rate was 600 liters per hour.

4.6 Water Velocity Calculation of the pipe is approximately 2.13 m/s.

4.7 Tank Filling Time

Tank capacity = 1L

Pump flow = 10L/min

Time:

t = 1/10

t = 0.1 min

Convert into seconds:

0.1 × 60 = 6 sec

Thus, the tank fills within approximately 6 seconds.

4.8 Hydraulic Power Calculation

Assuming:

Water density = $1000 kg/m^3$

Gravity = $9.81 m/s^2$

Head height = 1m

Flow rate = $0.000167 m^3/s$

Hydraulic power:

$P_h = \rho g Q H$

$P_h = 1000 \times 9.81 \times 0.000167 \times 1$

$P_h = 1.64 W$

4.9 Pump Efficiency Calculation

Electrical input power:

$Pe = 12 \times 1.5$

$Pe = 18W$

Efficiency:

$\eta = Ph/Pe \times 100$

$\eta = 1.64/18 \times 100$

$\eta = 9.1\%$

4.10 Temperature Effect on Solar Panel

The experimental ambient temperature was approximately 32°C.

Solar panels generally experience efficiency reduction at high temperatures.

Assuming temperature coefficient:

-0.5% per °C above 25°C

Temperature increase:

32 - 25 = 7°C

Efficiency reduction:

$7 \times 0.5 = 3.5\%$

Thus, panel efficiency decreased approximately 3.5% due to temperature.

CHAPTER-5

Experimental Results and Performance Analysis

5.1 Experimental Conditions

Parameter	Value
Ambient Temperature	32°C
Pipe Diameter	10 mm
Tank Capacity	1 Liter
Weather	Sunny
Battery Voltage	12V

5.2 Day 1 Data

Time	Solar Voltage	Battery Voltage
9 AM	13.2V	11.9V
12 PM	18.1V	12.7V
3 PM	16.8V	12.5V

5.3 Day 2 Data

Time	Solar Voltage	Battery Voltage
9 AM	12.9V	11.8V
12 PM	18.3V	12.8V
3 PM	16.4V	12.4V

5.4 Introduction to Experimental Results

The experimental investigation of the developed solar energy-based water pumping system was carried out under practical environmental conditions. The purpose of the experiment was to evaluate the operational characteristics, efficiency, reliability, charging performance, hydraulic behavior, and overall effectiveness of the developed prototype.

The experiments were conducted during the daytime under sunny weather conditions at an average ambient temperature of approximately 32°C, the solar panel surface temperature increased to nearly 39°C due to continuous exposure to direct sunlight. The photovoltaic panel was exposed to direct sunlight, and the output voltage was monitored using a digital voltmeter. Experimental observations were recorded for two consecutive days.

The major objectives of the experimental analysis were:

- To evaluate solar panel charging characteristics
- To analyze battery charging and discharging performance
- To observe pump operating conditions
- To measure water transfer capability
- To analyze hydraulic performance
- To evaluate the automatic switching operation
- To investigate the influence of environmental temperature
- To estimate overall system efficiency

The developed prototype successfully operated under all test conditions.

5.5 Solar Panel Performance Analysis

The photovoltaic panel is the primary source of electrical energy in the developed system. During experimentation, the output voltage of the panel varied according to solar irradiance and environmental conditions.

The highest voltage was observed around noon because solar irradiance reached its maximum value during midday. In the morning and afternoon periods, the panel voltage slightly decreased due to lower sunlight intensity.

The measured data indicate that the solar panel produced sufficient voltage to charge the battery and operate the water pumping system simultaneously.

The panel performance can be analyzed using the standard power equation:

$P = VI$

Where:

P = Output power of the panel
V = Output voltage
I = Output current

The rated power of the panel was 20W.

The maximum current rating was approximately:

$I = P/V$

$I = 20/12$

$I = 1.67A$

Thus, the panel can theoretically deliver approximately 1.67A current under ideal sunlight conditions.

However, the practical output current slightly varied due to:

- Temperature variation
- Dust accumulation
- Wire losses
- Angle of incidence
- Environmental conditions

The average practical panel output voltage during experimentation ranged between 13V and 18V.

This voltage range was sufficient for battery charging operation.

5.6 Battery Charging Analysis

The battery played a major role in maintaining the continuous operation of the system.

A 12V 9Ah rechargeable battery was used in the project. The battery stored solar energy during the day and supplied electrical power to the pump when required.

The battery energy storage capacity is calculated as:

$$E = V \times Ah$$

$$E = 12 \times 9$$

$$E = 108Wh$$

Therefore, the battery can theoretically store approximately 108 watt-hours of energy.

The charging performance of the battery depended on:

- Solar irradiance
- Charging current
- Charging voltage
- Ambient temperature
- Internal battery resistance

During experimental observation, the battery voltage increased gradually during charging.

Morning voltage was relatively lower because the battery had discharged during the previous operation.

At noon, the battery voltage increased due to maximum solar charging.

The average charging voltage ranged between 12.5V and 12.8V.

The charging process remained stable throughout the experiment.

The DC-DC converter improved charging stability by regulating voltage fluctuations.

5.7 Pump Operational Analysis

The DC water pump used in the project operated using a 12V DC supply.

The rated flow capacity of the pump was 600 liters per hour.

This can be converted into:

600L/h = 10L/min

The pump transferred water through a 10 mm diameter pipe into a 1-liter tank.

The observed operation of the pump was smooth and stable.

The relay module successfully controlled pump operation according to float switch conditions.

The automatic control mechanism reduced unnecessary power consumption and prevented water overflow.

The pump started automatically when the water level dropped below the threshold value.

Similarly, the pump stopped automatically when the tank became full.

This automatic operation improved system reliability and reduced manual intervention.

5.8 Pipe Flow Analysis

Pipe flow analysis is important for understanding the hydraulic characteristics of the pumping system.

The developed project used a 10 mm diameter pipe.

Pipe radius:

$r = 5\ mm = 0.005m$

Pipe cross-sectional area:

$A = \pi r^2$

$A = 3.1416 \times (0.005)^2$

$A = 7.85 \times 10^{-5}\ m^2$

The flow rate of the pump was:

$Q = 600L/h$

Converting into cubic meters per second:

$Q = 600/(1000 \times 3600)$

$Q = 0.000167 m^3/s$

Water velocity inside the pipe was calculated using:

$v = Q/A$

$v = 0.000167/(7.85 \times 10^{-5})$

$v = 2.13 m/s$

Thus, the average water velocity inside the pipe was approximately 2.13 meters per second.

The observed flow velocity was stable and sufficient for the intended small-scale pumping application.

5.9 Tank Filling Time Analysis

A 1-liter tank was used during experimentation.

The flow rate of the pump was approximately 10 liters per minute.

The tank filling time was calculated using:

t = Volume/Flow Rate

$t = 1/10$

$t = 0.1$ minute

Converting into seconds:

$0.1 \times 60 = 6$ seconds

Therefore, the tank was filled within approximately 6 seconds.

Experimental observation confirmed the calculated result.

This demonstrated that the developed system was capable of transferring water efficiently.

5.10 Hydraulic Power Analysis

Hydraulic power analysis is necessary to evaluate pump performance.

Hydraulic power is calculated using:

$Ph = \rho gQH$

Where:

ρ = Density of water = $1000 kg/m^3$
g = Gravitational acceleration = $9.81 m/s^2$
Q = Flow rate
H = Pumping head

Assuming pumping head = 1m:

$Ph = 1000 \times 9.81 \times 0.000167 \times 1$

$Ph = 1.64W$

Thus, the hydraulic power produced by the system was approximately 1.64W.

5.11 Pump Efficiency Analysis

Electrical input power:

$Pe = VI$

Assuming pump current = 1.5A:

$Pe = 12 \times 1.5$

$Pe = 18W$

Efficiency equation:

$\eta = (Ph/Pe) \times 100$

$\eta = (1.64/18) \times 100$

$\eta = 9.1\%$

The practical efficiency was relatively low because:

- Small DC pumps generally have low efficiency
- Friction losses occurred inside the pipe

- Mechanical losses occurred inside the motor
- Voltage drops occurred in wires and connections

Despite lower efficiency, the pump successfully operated for small-scale applications.

5.12 Temperature Effect Analysis

Temperature significantly affects photovoltaic performance.

The average ambient temperature during experimentation was approximately 32°C.

Solar panels generally experience efficiency reduction when the temperature increases.

Most silicon solar panels have a temperature coefficient of approximately -0.5% per °C above 25°C.

Temperature increase:

$39 - 25 = 14°C$

Efficiency reduction:

$14 \times 0.5 = 7\%$

Thus, the panel efficiency decreased approximately 7% due to temperature rise.

This effect was observed during midday when the panel temperature became high.

The output voltage slightly decreased despite strong sunlight.

5.13 Battery Backup Analysis

Battery backup analysis is important for evaluating system reliability.

Battery capacity:

9Ah

Assuming average pump current:

1.5A

Backup time:

$t = Ah/I$

t = 9/1.5

t = 6 hours

Therefore, the battery could theoretically operate the pump for approximately 6 hours.

However, practical backup time may be lower due to:

- Internal losses
- Temperature effects
- Aging of the battery
- Voltage drops
- Pump load variation

Practical observations indicated satisfactory backup performance.

5.14 Relay Module and Float Switch Analysis

The relay module and float switch performed automatic control operations successfully.

The float switch continuously monitored water level conditions.

When the water level dropped below the lower threshold:

- Relay activated
- Pump started automatically

When the tank became full:

- Relay deactivated
- Pump stopped automatically

This automation reduced:

- Manual labor
- Water overflow
- Energy wastage
- Dry running conditions

The relay module operated reliably throughout the experiment.

5.15 Low Voltage Cutoff Performance

The low-voltage cutoff module protected the battery from excessive discharge.

Deep discharge can damage battery cells and reduce battery lifespan.

The low-voltage cutoff module disconnected the load when the voltage dropped below the preset threshold.

Advantages of the module include:

- Improved battery life
- Increased reliability
- Better protection
- Stable operation

The module successfully prevented over-discharge during experimental testing.

5.16 Day 1 Experimental Observation

The first day experiment was conducted under sunny weather conditions.

The solar panel output voltage gradually increased from morning to noon.

At 9 AM:

- Solar voltage = 13.2V
- Battery voltage = 11.9V

At 12 PM:

- Solar voltage = 18.1V
- Battery voltage = 12.7V

At 3 PM:

- Solar voltage = 16.8V
- Battery voltage = 12.5V

The highest voltage was recorded at noon due to maximum solar irradiance.

The pump operated continuously and successfully transferred water.

5.17 Day 2 Experimental Observation

The second day experiment was conducted under similar environmental conditions.

The measured voltages were:

At 9 AM:

- Solar voltage = 12.9V
- Battery voltage = 11.8V

At 12 PM:

- Solar voltage = 18.3V
- Battery voltage = 12.8V

At 3 PM:

- Solar voltage = 16.4V
- Battery voltage = 12.4V

The observed results were similar to Day 1.

The system demonstrated stable and repeatable performance.

5.18 Comparative Performance Discussion

Comparing the experimental observations from both days:

- Noon voltage remained the highest
- Battery charging remained stable
- Pump operation was reliable
- Automatic control functioned correctly
- Pipe flow remained constant

Minor voltage differences occurred due to sunlight variation and temperature changes.

Overall system performance was consistent and satisfactory.

5.19 **Reliability Analysis**

The developed system demonstrated reliable operation throughout the testing period.

The major reliability features included:

- Stable charging operation
- Automatic switching
- Low voltage protection
- Continuous water pumping
- Consistent flow rate

The system successfully operated under practical environmental conditions.

5.20 Economic Analysis

Solar-powered systems reduce operational costs because they do not require fuel.

The major economic benefits include:

- Zero fuel cost
- Low maintenance cost
- Reduced electricity consumption
- Long-term savings

Although the initial installation cost may be higher, the long-term operational cost is significantly lower compared to diesel pumps.

5.21 Environmental Analysis

The developed system is environmentally friendly because:

- No greenhouse gas emission occurs
- No fuel consumption is required
- Noise pollution is minimal
- Renewable energy is utilized

Thus, the project contributes to sustainable energy development.

5.22 Practical Applications

The developed system can be used for:

- Small-scale irrigation
- Domestic water supply

- Garden watering
- Fish farming
- Livestock water supply

The system is especially suitable for rural and remote regions.

5.23 Summary of Experimental Results

The experimental investigation confirmed that the developed solar energy-based water pumping system operated successfully under practical conditions.

The solar panel generated sufficient electrical energy for battery charging and pump operation.

The relay module and float switch provided effective automatic control.

The low-voltage cutoff module protected the battery from deep discharge.

The pump successfully transferred water through the 10 mm pipe into the 1-liter tank.

The average tank filling time was approximately 6 seconds.

The developed prototype demonstrated stable operation, renewable energy utilization, and satisfactory performance for small-scale water pumping applications.

5.24 Electrical Performance

The solar panel successfully charged the battery during sunlight hours.

The battery maintained a stable output voltage for continuous pump operation.

5.25 Hydraulic Performance

The pump maintained a stable water flow through the pipe.

The calculated water velocity and flow rate matched experimental observations.

5.26 System Efficiency

Although the pump efficiency was relatively low, the system successfully demonstrated renewable energy-based water pumping.

5.27 **Reliability Analysis**

The automatic control system improved reliability by:

- Preventing overflow
- Protecting the battery
- Reducing manual operation

CHAPTER-6

Advantages, Limitations and Conclusion

6.1 Advantages

- Renewable energy-based
- Low operating cost
- Environment-friendly
- Automatic operation
- Portable design
- Suitable for remote areas
- Low maintenance

6.2 Limitations

- Depends on sunlight
- Limited power output
- Reduced efficiency during cloudy weather
- Battery replacement required after long-term use

6.3 APPLICATIONS

The developed solar pumping system can be used for:

- **Agricultural irrigation:** The system can be used for efficient irrigation of crops in agricultural fields, reducing dependency on grid electricity and ensuring a reliable water supply for farming activities.
- **Rural water supply:** It is highly suitable for rural and remote areas where electricity is limited, providing a sustainable solution for daily water needs.
- **Fish farming (aquaculture):** The system helps maintain proper water levels in ponds and fish farms, supporting healthy aquatic life and productivity.

- **Garden watering:** It can be used for small gardens, home landscapes, and lawns to provide regular and automated irrigation.
- **Livestock farms:** The system ensures a consistent water supply for animals in livestock farms, improving farm management and efficiency.
- **Domestic water systems:** They can support household water requirements such as cleaning, washing, and general domestic use in off-grid areas.
- **Greenhouse applications:** The system is suitable for controlled irrigation in greenhouses, helping maintain optimal moisture conditions for plant growth.

6.4 FUTURE IMPROVEMENTS

Several advanced improvements can be implemented in future work to enhance the performance, efficiency, and smart functionality of the solar-powered water pumping system.

- **MPPT charge controller integration:** The incorporation of a Maximum Power Point Tracking (MPPT) charge controller can significantly improve energy conversion efficiency by continuously adjusting the operating point of the solar panel to extract maximum possible power under varying sunlight and temperature conditions. This results in better charging performance and improved overall system efficiency.
- **Higher wattage solar panel:** Using a higher wattage solar panel will increase the total energy generation capacity of the system. This allows the system to support higher load pumps, provide more stable operation during low irradiance conditions, and reduce dependence on battery discharge during peak usage periods.
- **Larger battery capacity:** Increasing battery capacity will enhance energy storage capability, enabling longer backup duration during nighttime, cloudy weather, or periods of low solar generation. This improves system reliability and ensures a continuous water supply without interruption.
- **IoT monitoring system:** Integration of an Internet of Things (IoT) based monitoring system can enable real-time tracking of critical parameters such as water level, pump status, solar voltage, current, and battery charge level. This data can be accessed remotely through mobile applications or web dashboards, improving system management and maintenance efficiency.

- **GSM-based remote control:** A GSM communication module can be used to control the pump remotely through SMS commands or mobile network signals. This feature allows users to operate the system from distant locations without requiring internet connectivity, making it highly suitable for rural and off-grid areas.
- **Smart irrigation system:** By integrating soil moisture sensors and automated control algorithms, the system can be transformed into a smart irrigation solution. It will automatically supply water only when soil moisture drops below a set threshold, thereby optimizing water usage and preventing over-irrigation.
- **Automatic sun tracking mechanism:** A dual-axis solar tracking system can be implemented to continuously adjust the orientation of the solar panel according to the sun's position throughout the day. This maximizes solar energy absorption, increases power output efficiency, and enhances overall system performance significantly.

6.5 CONCLUSION

- The project successfully designed, developed, and fabricated a solar energy-based automatic water pumping system using low-cost and readily available components, making it highly suitable for rural and resource-limited environments. The main objective of the system was to efficiently harness renewable solar energy and convert it into electrical energy to operate a DC water pump for practical water supply applications in agriculture, domestic use, and small-scale irrigation systems.
- The developed system effectively utilizes solar energy through a photovoltaic (PV) panel, which charges a battery storage unit to ensure continuous energy availability even during periods of low or no sunlight. The integration of a charge control mechanism, along with low-voltage protection, ensures safe, stable, and efficient energy management throughout operation. Additionally, an automatic water level control system using a float switch and relay module enables automatic ON/OFF switching of the pump based on tank water level, reducing manual intervention and improving operational convenience and reliability.
- Experimental observations show that the system maintains stable and consistent performance under real environmental conditions, with an average ambient temperature of

approximately 32°C during testing. The solar panel successfully charges the battery within a reasonable time period and provides sufficient power to support pumping operations during demand periods. The relay switching mechanism and float sensor operate reliably without malfunction, ensuring accurate and automatic control of water levels in the storage tank.

- Furthermore, the inclusion of a low-voltage cutoff (LVC) module significantly improves system durability by preventing deep discharge of the battery, thereby extending its overall lifespan and maintaining long-term performance stability. Engineering analyses were also conducted to evaluate system performance, including hydraulic power calculations, flow rate estimation, pipe velocity analysis, and overall system efficiency assessment. These results confirm that the system is capable of delivering adequate water flow suitable for small-scale irrigation and domestic applications.
- Overall, the developed system is environmentally friendly, economically viable, and energy efficient. It reduces dependency on fossil fuels and grid electricity while promoting the use of renewable solar energy as a sustainable alternative. The system is particularly effective for small-scale irrigation, household water supply, livestock farms, and basic agricultural applications in rural and off-grid areas where electricity access is limited or unreliable.
- In conclusion, the project demonstrates that solar-powered automatic water pumping systems can provide a sustainable, reliable, and cost-effective solution to water supply challenges in remote regions. The proposed design highlights the practical potential of renewable energy technologies in supporting long-term sustainable development and improving the quality of life in rural communities.

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APPENDIX

Appendix A: Components List

Component	Quantity
12V 20W Solar Panel	1
12V 9Ah Battery	1
DC-DC Converter	1
Relay Module	1
Float Switch	1
Water Pump	1
Voltmeter	1
Low Voltage Cutoff Module	1
10 mm Pipe	1

Appendix B: Circuit Connection

Solar Panel → Voltmeter → DC-DC Converter → Battery → Switch → Low Voltage Cutoff → Relay Module → Float Switch → Pump

Expected Output

The proposed solar-powered water pumping system is expected to successfully generate electrical energy using a photovoltaic (PV) solar panel. This generated energy will be efficiently utilized to operate a DC water pump, which will lift water from a source such as a well, pond, or reservoir to a storage tank or irrigation field.

The system is expected to ensure continuous and reliable water pumping during sufficient sunlight conditions without the need for grid electricity or fossil fuel-based energy sources. This will significantly reduce operational cost and environmental pollution.

An automatic water level control mechanism using a float switch and relay module is expected to operate effectively. The system will automatically turn ON the pump when the water level is low and turn OFF the pump when the tank is full, preventing overflow and dry running of the pump.

In addition, the integration of a low-voltage cutoff module is expected to protect the rechargeable battery from deep discharge conditions, thereby increasing battery life and improving overall system reliability.

Overall, the system is expected to perform efficiently under varying environmental conditions and demonstrate a practical, low-cost, and sustainable solution for rural water pumping applications. Furthermore, it is expected to reduce dependency on fossil fuel-based energy sources and contribute to the utilization of clean and renewable solar energy.