DESIGN AND PERFORMANCE EVALUATION OF A PARABOLIC REFLECTOR-ASSISTED HYBRID SOLAR-THERMAL UNIT FOR STEAM-BASED POWER GENERATION WITH INTEGRATED IOT CONTROL

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In partial fulfillment of the requirement for award of the degree

Of

Bachelor of Science in Mechanical Engineering

September, 2025

Approval

This is to certify that the Project and Thesis work (ME-400) titled "Design and Performance Evaluation of a Parabolic Reflector-Assisted Hybrid Solar-Thermal Unit for Steam-Based Power Generation with Integrated IoT Control," submitted by Md. Ashraful Alam Showrav (ID: ME2201026228), Md. Rayhan (ID: ME2201026290), Foisal Hossain (ID: ME2201026298), Md. Hafizur Rahman (ID: ME2201026210), and Md. Abdul Hamid (ID: ME2201026266), has been duly approved by the examiners. This thesis fulfills a portion of the requirements for the award of the degree of Bachelor of Science in Mechanical Engineering at Sonargaon University, Green Road, Dhaka.

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DECLARATION

We, the undersigned, hereby solemnly declare that the work presented in this project has been exclusively carried out by us and has not been previously submitted to any university or organization for the award of any degree or certificate.

We further affirm that the work presented does not violate any existing copyrights.

Moreover, we undertake to indemnify the university against any loss or damage resulting from any breach of the aforementioned obligations.

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ABSTRACT

The growing demand for clean energy has driven advances in solar power. While solar systems are common, they can be inefficient in remote areas due to inconsistent sunlight and alignment issues. This project introduces a hybrid solar-thermal power generation system that combines photovoltaic (PV) and thermal energy technologies with Internet of Things (IoT) features for better monitoring and control. The system uses a solar panel to convert sunlight into DC electricity, regulated by a charge controller and stored in a battery. A buck converter adjusts the voltage to power sensors and microcontrollers. To capture more solar energy, a dual Light Dependent Resistor (LDR)-based sun tracking system, controlled by an Arduino Nano and MG995 servo motor, keeps the panel oriented toward the sun. A parabolic reflector focuses solar energy onto a steam generation chamber, where water, pumped through copper pipes, is heated to produce steam. The water flow is managed by an automated system using a BC547 transistor and an ESP-32 microcontroller. The steam drives a micro-turbine to generate additional electrical power, which is monitored and stored by the ESP-32. Temperature sensors collect thermal data, and an inverter converts the stored 12V DC power to 220V AC for household use. The system is connected to the Blynk IoT platform for remote monitoring and control of power generation and load management via smartphone. The system's performance results show a thermal efficiency of 40%, electrical efficiency of 3.33% per hour, and an overall efficiency of 23.42%, combining both thermal and electrical performance. This hybrid system offers an efficient, sustainable solution for decentralized energy, especially in remote or off-grid areas. The IoT integration with real-time sun tracking enhances energy capture and conversion, making it a significant improvement in solar-thermal hybrid energy systems.

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CHAPTER -1

INTRODUCTION

1.1 Overview

This project introduces a pioneering, cost-effective IoT-integrated solar-thermal hybrid energy system featuring advanced real-time sun tracking. Designed for maximum solar energy capture, it ingeniously combines photovoltaic and thermal technologies. A key innovation is its sophisticated solar tracking mechanism, which continuously aligns the solar panel and its components with the sun's most direct rays, significantly enhancing energy conversion efficiency. The solar panel is integrated with a copper pipe assembly, enabling simultaneous electricity generation through photovoltaic conversion and thermal energy absorption. To boost thermal energy capture, an angled array of over a hundred small mirrors concentrates intense solar energy onto a metal steam generation jar. Water, pre-heated as it flows through the copper pipes, enters the steam jar, where the concentrated solar energy converts it into high-pressure steam [1]. This steam then powers a mini fan connected to a DC motor, acting as a compact steam-driven wind turbine to produce additional electrical energy. This innovative design effectively combines dynamic thermal management with advanced power generation, utilizing a dual-loop energy harvesting strategy that synergistically integrates direct photovoltaic conversion with thermally driven electricity generation [2], [3], [4]. Furthermore, an Arduino-based tracking device coupled with photovoltaic controls enables precise alignment and data logging, optimizing energy yield and facilitating system monitoring in both rural and urban environments [5].

For comprehensive automation and vigilant monitoring, the system employs an Arduino for essential operations like automatic water level management, alongside a NodeMCU for real-time data acquisition and seamless wireless communication. A DS18B20 temperature sensor meticulously monitors water temperature, while a voltage divider circuit accurately measures the voltage output from both the solar panel and the steam-powered turbine. These critical readings are displayed on an LCD screen and transmitted to the Blynk IoT application, enabling remote monitoring. The electrical energy generated by both the solar panel and the DC motor is stored in a battery bank, which powers the entire system. The inclusion of a DC to AC inverter further highlights the system's capability to power conventional AC appliances. This groundbreaking hybrid solar-thermal energy system effectively demonstrates the compact and cost-efficient utilization of multiple renewable

energy sources, emphasizing the crucial role of IoT in intelligent, real-time energy management [6]. By harmoniously integrating electricity generation, thermal energy utilization, smart monitoring, and storage, this project offers a comprehensive and highly scalable solution for diverse energy needs. Moreover, the synergistic integration of photovoltaic and thermal energy generation within a single system optimizes resource utilization. It enhances overall energy conversion efficiency, marking a significant advancement in sustainable energy solutions. This approach addresses the critical need for hybrid systems capable of simultaneously generating electricity and facilitating water purification or desalination, which is increasingly relevant for decentralized energy provision in remote or off-grid locations [7].

1.2 Problem Statement

Traditional solar systems, relying solely on photovoltaic or thermal technology, struggle to meet the rising global demand for clean energy due to limited efficiency and inconsistent supply. A key gap exists in the market for affordable, compact, and integrated hybrid energy systems that combine thermal and PV generation with real-time sun tracking and IoT capabilities, especially for educational and small-scale off-grid use. Existing options are often expensive or lack the intelligent monitoring and control needed for optimal energy yield. This research addresses this by developing a cost-effective hybrid system that uses integrated PV/T technology and sun tracking, enhanced by IoT for monitoring and control [2]. This approach aims to overcome the intermittency of renewables by integrating multiple generation methods, thus improving grid stability and energy independence, particularly in remote areas [8]. The system's design also addresses the need for resilient energy infrastructure in regions with unstable grids or limited access to power [9]. Such a hybrid system promotes energy independence and reduces reliance on conventional sources, supporting sustainable development [10]. It offers a pathway to decentralized energy generation, crucial for climate change mitigation and improving energy access in underserved communities [6]. By combining solar thermal and photovoltaic technologies, this hybrid design provides a more reliable and consistent energy output than single-source systems, mitigating the intermittency challenges of renewables [11]. The real-time sun tracking mechanism further boosts energy capture by optimizing the orientation of solar collectors, enhancing both PV and thermal efficiencies [12]. IoT integration enables real-time performance optimization, predictive maintenance, and remote diagnostics, maximizing uptime and energy yield. This comprehensive integration

results in a more efficient and reliable energy solution compared to standalone systems, encouraging broader adoption [13]. It allows for adaptive energy management and resource allocation, improving overall system efficiency and responsiveness [14]. Such systems also facilitate the decarburization of off-grid and remote regions by combining renewables with storage and backup, offering economic benefits over fossil fuels [15]. These advancements create a robust and sustainable energy platform, demonstrating a practical path toward reducing reliance on conventional energy [16]. This integrated approach addresses technical challenges and promotes wider adoption by offering a practical and economically viable solution for energy independence. Current solutions are often too expensive or lack advanced smart features, limiting their accessibility for low-income or rural applications. The intermittency of renewables like solar power necessitates robust energy storage and intelligent management for grid stability. There is a clear need for low-cost, modular, and integrated hybrid energy systems that are easy to build, maintain, and deploy, offering resilience and reducing reliance on traditional grids and fossil fuels. This project provides a practical, scalable solution that bridges theory and application, emphasizing both efficiency and educational value. [17] This study addresses these limitations by designing and demonstrating a cost-effective, IoT-integrated solar-thermal hybrid energy system with real-time sun tracking, thereby offering a pragmatic solution for distributed energy generation.

1.3 Aims

The primary objective is to develop a cost-effective, IoT-connected solar-thermal hybrid energy system with real-time sun tracking capabilities. This involves optimizing the design for energy collection efficiency, ensuring affordability through judicious material and manufacturing choices, and integrating IoT features for enhanced performance monitoring and control [18].

- The system aims to be a low-cost hybrid energy setup, combining solar electricity and heat generation technologies.
- It incorporates an innovative solar tracking system for efficient sunlight capture.
- A solar concentrator with mirrors focuses sunlight to generate steam.
- Copper pipes facilitate heat transfer and preheat water for steam production.
- A small turbine powered by steam generates supplementary electricity.

- An Arduino system automatically manages water levels in the steam generator.
- Real-time temperature and voltage are monitored using sensors like the DS18B20 and voltage divider circuits.
- IoT capabilities are implemented via NodeMCU and the Blynk platform for remote data visualization.
- Generated electrical energy is stored in batteries to power the system.
- The system can power both DC and AC devices by converting DC to AC power, enabling the operation of conventional appliances [19].
- The ultimate goal is to provide a self-sufficient and portable energy source for off-grid locations.
- This comprehensive approach ensures efficient energy harvesting and utilization, supported by a robust platform for real-time monitoring and control through IoT [20] [21].
- The main aim is to demonstrate that this integrated system is both affordable and functional, highlighting its potential as a sustainable and accessible energy option.
- This project addresses the need for independent energy systems capable of autonomous operation, reducing reliance on fossil fuels [22].
- This overall methodology enhances energy independence and environmental sustainability, paving the way for similar hybrid energy solutions.
- Furthermore, the system's flexible modular design and the use of standard components reduce manufacturing and setup costs, making it attractive for communities with limited financial resources [23]. This combination of affordability and effective performance positions the system as a practical solution for decentralized power, particularly in areas with the greatest need [19]. Such integrated systems also improve energy access and facilitate sustainable water supply projects in remote locations [24].

1.4 Objectives

The main objectives of this research are to build and test a working prototype, analyzing its cost-effectiveness and market potential. This includes evaluating durability, maintenance needs, and growth potential. The project also aims to enhance current hybrid energy systems by incorporating advanced controls and real-time data collection for improved energy management.

- Develop a hybrid energy system that integrates solar electricity and solar heat to produce both power and thermal energy, improving efficiency and flexibility.
- Incorporate smart automation with solar tracking, sensors, and Arduino-based controls to enhance performance and enable real-time monitoring.
- Design and implement thermal components including mirror concentrators, copper pipe pre-heating, and a steam generator for efficient steam production.
- Utilize steam-driven power generation by operating a turbine connected to a DC motor, while evaluating cost, durability, and market potential of the prototype.

1.5 Project Methodology

The project's methodology details a comprehensive strategy for the design, construction, and validation of an innovative IoT-enabled solar-thermal hybrid energy system featuring real-time sun tracking. This approach integrates robust hardware and software development, seamless sensor integration, efficient energy generation, and sophisticated IoT-based monitoring. The methodology adopted a structured pathway, commencing with conceptualization and meticulous component selection, including solar panels, copper piping, reflective mirrors, microcontrollers, sensors, and energy storage units. A sophisticated dual-axis solar tracking system, engineered with light-dependent resistors and servo motors under Arduino control, ensures continuous alignment of the solar panel and reflector mirrors with the sun, thereby maximizing energy capture throughout the day. Copper pipes integrated with the solar panel serve as a heat exchanger, preheating water as it circulates and effectively capturing solar thermal energy. A custom-designed reflector array, comprising over one hundred precisely angled small mirrors, concentrates sunlight onto a focal point, facilitating efficient steam generation within a metal chamber. Water, pumped from a reservoir through the copper pipes and into the steam chamber, is further heated by the concentrated sunlight, producing steam. This steam is directed towards a mini fan coupled with a DC motor, converting its kinetic energy into supplementary electrical power, mimicking a miniature turbine system. For adept system monitoring and control, both Arduino and NodeMCU microcontrollers were employed. The Arduino manages critical functions such as steam chamber water level regulation and pump operation. At the same time, the NodeMCU collates sensor data, including readings from a DS18B20 temperature sensor and a voltage divider circuit. This data is presented in real time on an LCD and transmitted to the Blynk IoT platform for accessible remote monitoring. All generated electrical energy, originating from both the solar panel and the steam-driven turbine, is stored in a rechargeable battery bank, which also powers essential system components like microcontrollers, sensors, and the pump. A DC to AC inverter connected to the battery demonstrates the system's capacity to power standard AC loads, such as a light bulb, highlighting its practical applicability. Rigorous testing was conducted under diverse sunlight conditions to ascertain performance, reliability, and efficiency, with iterative adjustments made to optimize system responsiveness and energy output. This holistic methodology culminates in a functional prototype that vividly illustrates the efficient dual utilization of solar energy—both electrical and thermal—enhanced by intelligent IoT-based monitoring and control capabilities. This integrated approach not only maximizes energy harvesting but also enables

comprehensive real-time data acquisition and remote management, critical for predictive maintenance and optimized performance in dynamic environmental conditions. The following sections delineate the detailed design specifications, implementation challenges, experimental results, and a comprehensive analysis of the system's overall performance and cost-effectiveness. This meticulous validation process involved analyzing parameters such as thermal efficiency, electrical power output, and the efficacy of the real-time tracking mechanism under varying solar irradiance levels. The comprehensive evaluation also extended to the system's longevity and adaptability to diverse climatic conditions, ensuring its robustness for prolonged operation in various geographical contexts.

Furthermore, the economic viability of this hybrid system was rigorously assessed, highlighting its potential to provide sustainable and affordable energy solutions, particularly in off-grid or remote areas. The system's modular design also facilitates scalability and integration with existing energy infrastructures, further broadening its potential applications beyond standalone installations. This multifaceted evaluation confirmed the system's robust performance across a spectrum of operational scenarios, providing a compelling case for its widespread adoption as a pragmatic and environmentally sound energy solution.

1.6 Quality Preservation

To ensure the long-term integrity and performance of the developed system, a comprehensive quality preservation strategy was implemented, focusing on material selection, robust construction techniques, and advanced thermal management. The selection of corrosion-resistant materials and hermetic sealing for critical components prevents degradation from environmental exposure, thereby extending the operational lifespan of the system components [25]. Advanced thermal management strategies, including passive and active cooling mechanisms, mitigate heat-induced stress on electronic and mechanical parts, maintaining optimal operating temperatures even under intense solar radiation. Moreover, specialized coatings were applied to reflective surfaces to resist oxidation and keep high specular reflectance over time, which is crucial for sustained energy concentration. Additionally, rigorous quality control protocols, including repetitive stress testing and accelerated ageing simulations, were employed to identify potential failure points and ensure the system's resilience under continuous operation, ultimately enhancing its reliability and cost-effectiveness over its projected lifespan [26]. This meticulous attention to detail in design and construction minimizes the need for frequent maintenance, further contributing to the system's economic attractiveness as a sustainable energy solution [27]. This comprehensive approach ensures that the system not only performs optimally but also maintains its efficiency and structural integrity throughout its operational life, offering a reliable and durable energy supply. The integration of IoT capabilities further enhances quality preservation by enabling real-time diagnostics and predictive maintenance, allowing for proactive intervention before minor issues escalate into significant failures. This proactive approach significantly reduces downtime and operational costs, demonstrating the synergistic benefits of IoT integration for long-term system sustainability [28]. This ensures the system's performance remains consistent over time, adapting to changing environmental conditions and operational demands [29].

1.7 Optimization Techniques and Scale-Up Considerations

These techniques range from advanced algorithms for maximizing power point tracking to intelligent control strategies for thermal energy utilization, aiming to achieve the highest possible energy yield from the available solar insolation. Furthermore, considerations for the scale-up of this prototype into larger, commercially viable systems are discussed, including modularity, manufacturing processes, and potential integration with existing grid

infrastructures. The analysis will also encompass the economic viability of large-scale deployment, evaluating initial investment costs against long-term operational savings and energy output benefits [30]. The discussion will further explore the potential for integrating artificial intelligence and machine learning algorithms to enhance predictive maintenance capabilities and dynamic optimization of energy dispatch, moving beyond conventional maximum power point tracking [31]. This predictive capability, utilizing historical and real-time data, allows the system to anticipate changes in solar irradiance and adjust its operation proactively, further enhancing efficiency and reliability [32]. The application of machine learning also extends to optimizing the overall energy management by balancing renewable energy generation with demand, thereby reducing reliance on conventional power sources and improving grid stability [33]. Such intelligent management systems, often enabled by IoT platforms, also facilitate the integration of diverse renewable energy sources and energy storage solutions, creating a more resilient and sustainable energy ecosystem [34]. This integration of AI and IoT transforms the system into an intelligent, self-optimizing entity, capable of making informed decisions for improved energy utilization and reduced operational costs. These AI-driven enhancements can also contribute to improved grid resilience, particularly in regions with prevalent digital infrastructure for renewable energy implementation [35]. This approach aligns with Industry 4.0 principles, emphasizing the integration of real-time monitoring and data analytics to overcome the intermittent nature of renewable energy sources and ensure a consistent supply.

CHAPTER-2

LITERATURE REVIEW

2.1 Introduction

The world's growing need for eco-friendly and sustainable energy has significantly advanced solar technology. Solar power is a big deal because it's everywhere, easy to access, and getting cheaper. This review examines the fundamentals and advancements in solar energy, including hybrid systems, key components, and their interplay to enhance overall performance. We're zeroing in on what this project is trying to improve. Checking out past research has given us some great ideas for this project. People discussing green energy often mention the need for systems that integrate various energy capture and conversion methods, along with real-time monitoring and control systems, to enhance efficiency and reliability [36]. This includes examining how AI and machine learning can strengthen performance and predictive capabilities in these systems, a relatively underexplored area for affordable, hybrid solar-thermal setups [37]. Plus, using AI models, especially hybrid ones, looks really promising for making grid stability checks better and improving how we integrate renewable energy, like with Python tools for watching solar energy networks live [38]. These AI methods enable us to predict energy output and demand more accurately, allowing us to tweak things in real-time and achieve optimal performance and grid integration [39]. AI can also help identify and resolve issues in photovoltaic systems early, allowing us to perform maintenance before problems arise and extend the lifespan of solar energy systems, running longer [40]. Basically, AI has come a long way since the mid-20th century, evolving from mere ideas to significantly impacting our lives [41]. This includes significant advancements in machine learning, deep learning, and language understanding, which are now being applied to tackle challenging problems in the renewable energy field [42]. AI algorithms can especially make smart grids work better, improve how energy is sent out, and make electrical systems stronger by allowing real-time adjustments and predictions [43]. When AI is used in renewable energy systems, such as solar-thermal hybrids, it can significantly improve our ability to predict energy production and distribution by analyzing factors like weather and energy consumption patterns [44]. Also, AI is crucial for making better decisions and can be integrated into energy sites to reduce costs and enhance efficiency, making it a must-have for future energy management [45]. This setup enables us to identify and address critical issues promptly, ensuring smooth operations and

informed decision-making about resource utilization and system enhancements [46]. On top of that, AI solutions help deal with the fact that renewable energy sources aren't always on by making it easier to hook them up to existing grids, which is key for making the electric grid more sustainable and secure [47]. The continuous progress in AI and machine learning gives us amazing opportunities to forecast precisely, optimize in real-time, and intelligently control complex energy systems, leading to better efficiency and lower operating costs [48]. AI's ability to sift through huge amounts of data and find tricky patterns also helps manage energy grids better, balancing what's available with what's needed, and cutting down on waste [44]. However, as AI becomes more common in intelligent energy systems, we need to think carefully about how it works and how it's managed to make sure it's used responsibly and reliably [49]. This review will also explore how AI and machine learning can be used for predicting maintenance, finding faults, and optimizing solar-thermal systems in real-time, showing how these intelligent algorithms can overcome the usual problems with renewable energy [50]. The teamwork between AI and IoT in smart grids offers excellent ways to boost energy efficiency and sustainability by allowing real-time monitoring, predictive analysis, and automatic control [51]. This combo is critical for hybrid solar-thermal systems, where making quick adjustments based on changing weather and energy needs can significantly enhance the system's overall performance and financial viability.

2.2 Context and Evolution of Hybrid Solar Energy Systems

The global shift towards sustainable and clean energy solutions has intensified interest in solar energy systems, given their environmental advantages, scalability, and decreasing costs. Solar energy can be harnessed in two primary forms: photovoltaic, which converts sunlight into electricity, and solar thermal, which captures solar heat for direct or indirect energy conversion [52]. Historically, traditional solar energy systems often relied solely on either PV or thermal technology, a design choice that inherently limited their overall energy utilization efficiency. This recognized limitation has prompted researchers to focus on hybrid solar-thermal systems as a promising solution [2]. These integrated systems aim to improve overall performance and energy yield by leveraging the complementary strengths of both photovoltaic and thermal technologies, thus enabling more comprehensive and efficient energy harvesting. The increasing demand for clean and sustainable energy has accelerated research into renewable energy technologies, especially in developing hybrid systems that integrate multiple energy harvesting methods. While traditional solar photovoltaic systems are widely used for electricity

generation, their efficiency can be constrained by factors such as panel orientation, temperature, and incident sunlight intensity [53], [54]. To address these limitations, hybrid approaches that combine PV and thermal systems (known as PVT systems) have been shown to improve overall efficiency by utilizing both the electrical and thermal output of the sun. A PVT system can achieve combined efficiencies greater than standalone PV or thermal systems, as discussed by Saini et al.

2.3 Key Technological Components and Their Integration

The efficiency of solar panels is highly dependent on the angle of incidence of sunlight. Fixed solar panels are only optimally effective for a small portion of the day, leading to significant periods of suboptimal energy collection. To overcome this limitation, solar tracking systems have been introduced to increase energy output by continuously adjusting the position of solar panels to follow the sun's path. Solar tracking systems, particularly dual-axis trackers, can significantly increase energy capture by maintaining the solar panel's orientation perpendicular to sunlight throughout the day. According to research by Azoumah et al. and Jain et al., solar tracking can increase energy collection by 30–45% compared to fixed installations. Studies such as those by Patel et al. further demonstrate that dual-axis tracking can increase solar energy capture by up to 40% compared to fixed panels. Most solar trackers utilize Light-Dependent Resistor sensors paired with servo motors and microcontrollers like Arduino for movement control based on sunlight intensity, ensuring continuous alignment for maximum energy capture throughout the day.

In conventional photovoltaic systems, a considerable portion of absorbed solar energy is dissipated as waste heat, which can actually reduce the electrical conversion efficiency of the PV cells. Photovoltaic-Thermal systems are designed to mitigate this issue by actively utilizing this heat rather than allowing it to dissipate. Research by Zondag et al. explored the integration of PV and thermal collectors, concluding that such hybrid systems offer improved energy conversion efficiency and better space utilization. In these systems, copper pipes or similar heat exchangers are typically placed beneath the solar panel. These components serve to capture the heat that would otherwise reduce PV efficiency, using it to preheat water or another working fluid. This integrated approach not only increases the overall system efficiency but also enables dual energy generation—electricity and heat—from the same physical setup [55].

To amplify the thermal component of solar energy systems, solar concentrators are employed to focus sunlight onto a smaller area, significantly increasing the energy flux and temperature at a focal point. Various types of solar concentrators exist, including flat mirrors, Fresnel lenses, and parabolic troughs [56]. Studies like those by Kalogirou and Hernandez et al. demonstrate that focusing sunlight dramatically increases the thermal energy available, making it viable for applications such as steam production or other high-temperature processes. Systems using heliostats or parabolic mirror arrays can significantly raise temperatures at a focal point, making steam generation viable even in small-scale setups. The concept of using multiple precisely angled mirrors to concentrate sunlight onto a single point is a scalable approach to enhance thermal energy capture [57].

The conversion of thermal energy into mechanical and subsequently electrical energy through steam-driven turbines is a well-established principle. Even at a small scale, this method provides an effective means of auxiliary power generation. Research by Deshmukh and More showed that even low-pressure steam, when directed at small fan blades connected to a DC motor, can generate measurable amounts of electricity. This concept supports the development of secondary energy harvesting mechanisms within hybrid systems, where steam produced from concentrated solar thermal energy powers a miniature turbine, effectively acting as a small-scale generator. Experimental setups utilizing DC motors connected to steam-driven turbines have consistently demonstrated the feasibility of producing electricity using mechanical motion generated from heated fluids or steam [58], [59].

The integration of the Internet of Things in renewable energy systems represents a significant advancement, enabling real-time data monitoring, remote control, and enhanced automation. Platforms such as Blynk and Thing Speak, in conjunction with microcontrollers like NodeMCU or ESP32, facilitate the seamless transmission of sensor data to cloud services and smart devices. Ahmed et al. emphasized the critical importance of IoT in developing smarter and more efficient energy systems by allowing users to remotely monitor vital parameters such as voltage, temperature, water levels, and overall system status. This capability is particularly beneficial in off-grid and remote setups where manual monitoring is impractical or challenging. Recent advancements in microcontrollers and IoT have further expanded the potential of renewable energy systems by enabling real-time monitoring, remote control, and automation. The incorporation of advanced sensors and microcontrollers with an IoT-based monitoring framework allows for real-time data analysis, which in turn enables adaptive control of energy

distribution based on consumption patterns and environmental conditions, thereby enhancing overall system efficiency and reliability [34].

Energy generated from intermittent renewable sources, such as PV panels and micro turbines, requires efficient storage solutions to ensure a continuous and reliable power supply. Battery banks are commonly employed for this purpose, accumulating surplus energy during periods of high generation and discharging it during periods of high demand. For applications requiring alternating current, a DC-to-AC inverter is essential to convert the direct current stored in batteries into usable AC power for household or commercial appliances. Research by Patel and Mehta on hybrid energy systems has underscored that properly integrated battery storage and power conversion systems are fundamental to making renewable energy systems reliable and suitable for standalone operation. These components ensure that the generated electricity can be effectively utilized for both DC and AC loads, showcasing versatility across various applications [19], [60]. Furthermore, the integration of smart inverters and IoT technologies within these storage systems enables dynamic regulation of voltage and power output, optimizing energy flow and grid stability [61].

2.4 Innovation Gap and Project Relevance

Even though solar energy technology has improved, there's still a significant gap in affordable, compact, and fully integrated hybrid energy systems. Most systems either focus only on PV or thermal, are pricey, or lack innovative features. It's especially hard to find systems that mix thermal and PV with real-time sun tracking and good IoT integration in a small, easy-to-understand package. This means we really need simple, modular, and integrated hybrid energy systems that are easy to build, fix, and use, especially for places with limited power or in rural areas. Building these kinds of systems is key to making energy more local and reliable, helping us avoid power outages and reduce our reliance on fossil fuels. Plus, since renewable energy sources like solar and wind aren't always steady, we need good energy storage to keep the power flowing reliably [62]. This project aims to address these issues by developing and demonstrating a cost-effective, IoT-ready solar-thermal hybrid energy system that tracks the sun in real-time, ideal for schools and small off-grid setups. It'll show how combining different renewable sources works well together and how real-time data can make energy capture and use much better [63]. It's not just about generating energy; it's also about making it beneficial for learning and understanding how energy systems work. This project helps more people use sustainable energy by offering a practical and straightforward way to build hybrid systems, connecting what students learn with what they can actually do. The system's modular design means it can be scaled up or down for different energy needs, making it flexible for various small-scale uses. We also want to share this as an open-source project so others can copy and improve it, boosting innovation in renewable energy and speeding up the use of similar sustainable tech. So, this project fills the innovation gap by providing a real, affordable prototype that combines the latest IoT technology with innovative solar energy solutions to boost efficiency and access. This all-in-one approach helps with energy independence and teaches people more about clever energy use, supporting global goals for sustainability and energy access [30]. It could be instrumental in places like Bangladesh, which receives a lot of sun and is trying to bring power to more rural areas [64]. The cost-effectiveness of these systems for rural communities, especially in Africa and Asia, has been demonstrated through projects utilizing hybrid renewable resources, such as solar and biomass, to provide affordable, reliable electricity [64]. These systems are vital for tackling energy poverty and promoting sustainable development where grid power is scarce [65]. This project aims to close the innovation gap by giving a real, affordable prototype that combines advanced IoT tech with proven solar energy methods to maximize efficiency and accessibility. This integrated solution

represents a significant step towards addressing widespread energy inequality, particularly in scattered rural areas where extending the primary grid is challenging, thereby underscoring the value of local, innovative energy solutions [66]. Making it affordable and adding real-time sun tracking make the system more practical and help overcome common hurdles to using renewable energy more widely. Also, by using advanced control algorithms for real-time sun tracking, the system gets more energy throughout the day, increasing its overall efficiency and output, which helps deal with the unpredictable nature of solar power. This comprehensive method, combining different energy sources with innovative management, offers a solid path to sustainable and resilient energy systems, especially for micro grids [67].

CHAPTER-3

MATERIALS AND METHODS

3.1 Methodology

This research outlines our approach to building an IoT-powered hybrid energy system that integrates solar and thermal technologies, featuring real-time sun tracking. We're using a setup that captures energy from both PV and thermal sources, with a dual-axis tracker and a steam generator that uses concentrated sunlight to grab as much energy as possible. Arduino and NodeMCU microcontrollers handle operational controls, such as water flow, and check in with IoT data. We'll be evaluating how well the system performs in terms of energy efficiency, reliability, and whether it makes financial sense under different conditions. On top of that, we're exploring ways to enhance the system and make it easier to scale up, particularly for areas off the primary grid or in rural regions. Our approach combines real-world testing with computer modelling to gain a solid understanding of how the system works and how it could be used more broadly. This method really helps us dive deep into how the system can boost energy capture through its real-time solar tracking, a trick that's proven to increase power generation by keeping up with the sun's movement [66]. This is crucial for addressing the inconsistent nature of renewable energy sources and enhancing the overall system stability [67]. Plus, by adding IoT bits, we can keep an eye on things constantly and make adjustments on the fly, letting the system adapt to changing weather and how much power is needed, which makes managing and distributing energy much smoother.

3.1.1 Conceptualization and Design

The system was conceptualized to efficiently integrate photovoltaic and thermal energy harvesting within a compact IoT-enabled framework, thereby maximizing energy yield. A dual-axis solar tracking mechanism was meticulously designed to follow the sun’s trajectory with precision, ensuring optimal sunlight exposure throughout the day. The thermal unit was coupled with high-conductivity copper piping and an efficient steam generation system to enable simultaneous electricity and heat production. Advanced control algorithms, developed using Arduino and NodeMCU microcontrollers, were implemented to automate critical

operations, including water flow, temperature regulation, and precise panel orientation adjustments. This crucial design stage focused on establishing a robust blueprint that harmoniously balanced peak energy efficiency, unwavering system reliability, and practical, real-world feasibility.

3.1.2 Material Selection

Materials were meticulously chosen to ensure optimal performance, durability, and cost-effectiveness. Copper pipes were selected for their superior thermal conductivity, polycrystalline solar panels for efficient electricity generation, and high-grade insulating materials to minimize energy loss. Sensors for temperature, flow, and solar intensity were chosen for their precision and seamless compatibility with IoT integration. Furthermore, the selection process rigorously considered environmental sustainability and long-term reliability, ensuring that all components could withstand prolonged operational conditions without significant performance degradation.

3.1.3 Prototyping and Fabrication

Following the conceptual design and material selection, a robust working prototype was fabricated. The assembly integrated solar panels, copper piping, sensors, and microcontroller units into a compact, highly functional structure. The IoT-based monitoring system was implemented to meticulously capture real-time data on energy output, temperature, and solar tracking efficiency. Prototyping facilitated iterative testing, enabling the swift identification of design bottlenecks and precise fine-tuning of mechanical and electronic components. This critical stage conclusively validated the design’s practical feasibility, assuring that the system could consistently deliver reliable energy harvesting while remaining highly scalable for potential future applications. This iterative process allowed for the refinement of the solar tracking algorithm, enhancing its ability to maximize energy capture by accurately adjusting the panel's orientation in response to the sun's movement [68].

3.2 Experimental Setup and Equipment

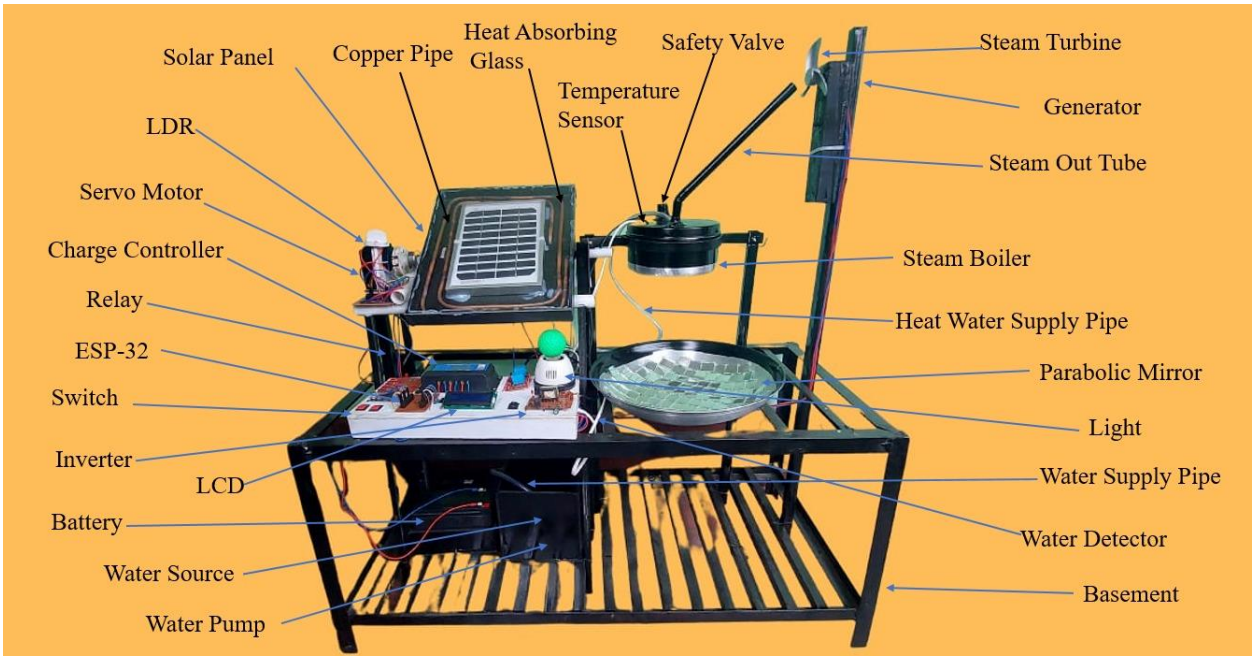


Fig 3.1: Experimental Diagram of proposed System

3.3 Experimental Equipment

The proposed IoT-Integrated Solar-Thermal Hybrid Energy System with Real-Time Sun Tracking is made of several components and they are:

- Solar Panel
- Copper Pipe
- Battery
- Charge Controller
- DC Motor
- Mirror
- Arduino Nano
- Gear Motor
- Mini Water Pump
- Inverter
- DS18B20 - Temperature Sensor
- Node MCU
- Relay
- Metal Box

- DC Bulb
- AC Bulb
- Plastic Pipe

3.3.1 Solar Panel

A solar panel is a device designed to convert sunlight into electricity. It achieves this through the photovoltaic effect, utilizing numerous solar cells, typically made of silicon, to absorb solar energy and generate direct current electricity. This DC electricity is then transformed into alternating current by an inverter, making it suitable for powering homes, businesses, and various other electrical systems.

3.3.1.1 Key aspects of solar panels include:

- **Placement:** They are commonly installed on rooftops or in open areas to maximize exposure to sunlight.
- **Energy Source:** Solar panels provide a clean, renewable energy source, helping to reduce reliance on fossil fuels.
- **Economic Benefit:** Their use can lead to lower electricity bills.

- **Energy Storage:** In some systems, batteries are integrated to store excess energy, ensuring power availability during periods of low sunlight, such as at night or on cloudy days.



Figure 3.2: Solar Panel

3.3.2 ESP-32

The ESP32, a popular and affordable microcontroller for IoT devices, features built-in Wi-Fi and Bluetooth. It has a dual-core processor, ample RAM, and various peripherals like SPI, I²C, and ADC. Its efficient power management, including deep sleep modes, makes it suitable for battery-powered applications.

3.3.2.1 Key specifications and features of the ESP32 include:

- Processor: A 32-bit LX106 RISC processor.
- Operating System Support: Supports Real-Time Operating Systems.
- Clock Frequency: Adjustable from 80 MHz to 160 MHz
- Memory: 1280 KB of RAM and 4 MB of flash memory.
- Connectivity: Integrated Wi-Fi and Bluetooth.
- Power Management: Supports deep sleep modes for energy efficiency.

- Origin: Developed by Espressif, a Chinese company.



Figure 3.3: ESP-32 Micro controller

3.3.3 Relay

A relay is essentially an electrically controlled switch. It uses a small electric current to manage much larger currents. When voltage is applied to its coil, small current flows, which then moves the contacts to allow a larger current to pass to an electrical device. Relays act like remote-controlled switches, turning circuits on or off based on outside electrical signals.

The idea behind a relay in electronics is similar to a relay race: a signal is received and then passed on to another part by flipping a switch. For example, when you press a button on a TV remote, it sends an electrical signal that triggers a relay in the TV, turning it on.

3.3.3.1 Key features of relays:

- **Purpose:** They are vital for safely controlling high-power circuits using low-power signals.
- **How they work:** An electrical signal to a coil creates a magnetic field, which physically moves switch contacts to either close or open a circuit.

- **Flexibility:** Relays come in many types, designed for different amounts of current and for controlling multiple circuits at once.
- **Uses:** They are common in many electrical and electronic systems, from simple electronics to complex industrial controls.



Figure 3.4: Relay

3.3.4 Battery

A 12V 7A rechargeable battery is a common power storage unit for backup and solar systems. Its durable plastic casing protects the internal components, which typically include lead plates in an electrolyte solution for lead-acid batteries. More advanced types use gel or fiberglass mats, making them spill-proof and resistant to vibration and temperature changes.

3.3.4.1 Key features of Battery:

- **Voltage** → 12 Volts (nominal output).
- **Capacity** → 7 Ampere-hours (Ah), supplies 7A for 1 hour or 1A for 7 hours.
- **Type** → Lead-acid (SLA/VRLA), Gel, AGM, or Lithium-ion.
- **Design** → Sealed, spill-proof casing; maintenance-free.
- **Durability** → Resistant to vibration, shocks, and temperature changes.
- **Applications** → Widely used in UPS, solar systems, emergency lights, and backup power.



Figure 3.5: Battey 12V, 7A

3.3.5 Charge Controller

A solar charge controller is essential for solar power systems, regulating the flow of electricity from solar panels to the battery. It safeguards the battery by preventing overcharging and deep discharging, thereby extending its lifespan. This device monitors the battery's voltage and adjusts the power received from the solar panels accordingly. There are two primary types:

- **PWM controllers:** These are generally more affordable and suited for smaller systems. They reduce the power supplied to the battery as it becomes fully charged.
- **MPPT controllers:** These are more efficient and designed for larger systems. They optimize power output by matching the voltage of the solar panels to that of the battery.

  Contemporary charge controllers offer several advanced features:
- **Connectivity:** Options include displays, LEDs, or wireless connectivity (Wi-Fi/Bluetooth) for monitoring and remote control.
- **Load Control:** The ability to switch connected devices on or off based on the battery's charge level or a pre-set schedule.

- **Protection Mechanisms:** Safeguards against issues like short circuits, reverse polarity, overheating, and overcurrent.

Effective power management through a solar charge controller enhances battery longevity, overall system health, and energy efficiency across all types of solar installations.



Figure 3.6: Solar Charge Controller

3.3.6 DC Motor

A **Direct Current motor** converts direct current electricity into mechanical motion. It works on the principle that a current-carrying wire in a magnetic field moves. The main parts are the stator (stationary magnet), rotor (rotating part), commutator and brushes (reverse current for continuous rotation), and windings (wire coils). When voltage is applied, current flows through the windings, creating a magnetic field that interacts with the stator's field, causing rotation.

DC motors are popular because they offer precise speed control, are easy to use, and respond quickly. They come in **two** main types:

- **Brushed DC Motors:** Cheaper and simpler, but wear out faster.
- **Brushless DC Motors:** More efficient, last longer, and are quieter.

Common uses include fans, pumps, robots, electric cars, and toys. Their speed and direction can be controlled electronically, for example, with Arduino microcontrollers. DC motors are key for systems needing compact, adjustable, and efficient movement.



Figure 3.7: Free DC Motor

3.3.7 Mirror

A mirror is a reflective surface, most commonly made from glass coated with a thin layer of metal, such as silver or aluminum. Its primary function is to reflect light and form images. In the context of solar energy, mirrors are crucial for reflecting and concentrating sunlight onto solar panels or thermal collectors, which significantly enhances the system's efficiency by increasing light intensity.

This technique, often seen in solar concentrators or solar thermal systems, helps maximize solar energy capture within a smaller area, leading to greater electricity generation or heat output. The mirrors used in these systems can be flat or curved (e.g., parabolic) to precisely focus the sunlight.

Beyond energy applications, mirrors are widely used:

- **Everyday Life:** For personal grooming, decorative purposes, and in various optical instruments.
- **Scientific and Technical Systems:** Valued for their ability to redirect and manipulate light, they are found in photography, astronomy, and even architecture.

- **Maintenance:** For optimal performance in technical systems, mirrors must be kept clean and accurately aligned.



Figure 3.8: Mirror

3.3.8 Arduino Nano

The Arduino Nano is a small, versatile microcontroller board using the ATmega328P chip. It's great for projects needing automation, data collection, or control, especially where space is tight. It offers similar functions to the Arduino Uno but in a smaller package.

3.3.8.1 Key features:

- **Processor:** ATmega328P
- **I/O Pins:** 14 digital, 8 analog
- **Clock Speed:** 16 MHz
- **Connectivity:** USB for programming and power
- **Voltage Regulation:** Onboard regulator
- **Programming:** Uses the Arduino IDE for easy code uploading to control components like sensors, motors, LEDs, and relays.
- **Communication:** Supports I2C and SPI for connecting to various modules.
- **Applications:** Suitable for sensor monitoring, robotics, and IoT projects due to its size, low power use, and adaptability.

- **Accessibility:** Cost-effective with strong community support, good for beginners and experts.

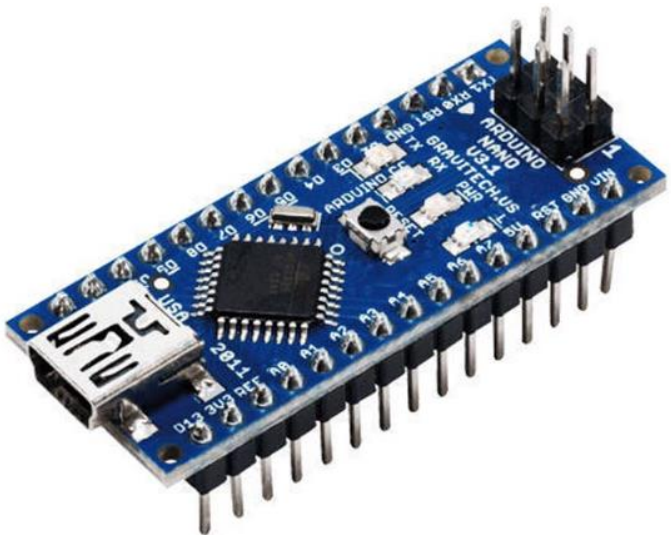


Figure 3.9: Arduino Nano

3.3.9 Servo Motor

The MG995 (made by TowerPro among others) is a high-torque hobby servo motor with metal gears, commonly used in RC (radio control) models, robotics, automation projects, etc. It offers a good balance of strength, durability, and cost, which is why it's popular among hobbyists.

Some of the strengths and common uses:

- **High torque for its size:** Metal gears + relatively high torque makes it good for moving heavier loads (arms, steering, etc.) in robotics.
- **Durability:** Metal gears + dual ball bearings (in many versions) help with wear, backlash, and load resistance.
- **Standard control interface:** Uses PWM control, compatible with typical hobby controllers and microcontrollers (e.g. Arduino, ESP32 etc.).
- **Common / widely available:** Parts like servo arms and mounting hardware are easy to find.

Typical applications might include RC cars, airplanes/helicopters, robotic arms, pan/tilt camera mounts, etc.



Figure 3.10: Servo Motor

3.3.10 Mini Water Pump

A 5V mini water pump is a small, low-voltage electric pump for moving or circulating water in small systems. It runs on 5V DC from sources like USB adapters or batteries. These pumps are light, energy-efficient, and good for DIY projects, automated watering, mini fountains, cooling, or solar irrigation.

3.3.10.1 Specifications:

- **Power:** 5V DC
- **Mechanism:** Motor-driven impeller
- **Flow Rate:** 80-120 liters/hour
- **Lift Height:** 0.5-1.2 meters
- **Design:** Usually submersible
- **Construction:** Waterproof plastic
- **Integration:** Easy with microcontrollers via relays or transistors
- **Reliability:** Good for small liquid transfer
- **Limitations:** Not for hot, corrosive, or dirty water unless rated.



Figure 3.11: Mini Water Pump

3.3.11 Inverter

A 12V to 220V inverter changes 12-volt DC power to 220-volt AC power, the common household voltage. This makes it useful for places without grid power, backup power, or portable power needs, allowing the use of standard appliances from a battery or solar setup. Internally, it boosts the 12V DC and converts it to AC using electronics. There are two main types:

- **Modified Sine Wave**: Cheaper, good for basic electronics.
- **Pure Sine Wave**: Cleaner power, needed for sensitive items like laptops or motors. For safety, inverters have protection against overvoltage, low batteries, short circuits, and overheating. Many also include USB ports and AC outlets.

To work well, it needs a battery (like a 12V 7Ah or bigger) and the total power used by devices shouldn't be more than the inverter's limit. This device is very helpful in remote areas or during power outages, offering energy independence.



Figure 3.12: Inverter Circuit

3.3.12 DS18B20 – Temperature Sensor

The DS18B20 is a digital temperature sensor used in electronics and automation for its accuracy and simple digital output. It uses the 1-Wire protocol, allowing multiple sensors on one microcontroller pin. Key specifications:

- Protocol: 1-Wire
- Range: -55°C to +125°C
- Accuracy: ±0.5°C (-10°C to +85°C)
- Power: 3.0V–5.5V external, or parasitic power from data line.
- Unique ID: Each sensor has a 64-bit serial code for bus compatibility.
- Output: Digital temperature readings, simplifying integration.
- Integration: Works with Arduino, Raspberry Pi, ESP8266.
- Applications: Waterproof versions for liquid monitoring, greenhouses, HVAC, solar water heaters, and weather stations.
- Programming: Uses libraries like OneWire and DallasTemperature in Arduino IDE.
- Advantages: Reliable, low-cost, and easy to use.



Figure 3.13: DS18B20 - Temperature Sensor

3.3.13 Metal Box

A metal box with a cover serves as a protective enclosure for electronic components, shielding them from damage, dust, moisture, and interference. Within this solar heating setup, it specifically functions as a heat absorption and storage unit, heated by a parabolic mirror. Constructed from robust metals such as aluminum or stainless steel, it provides essential strength and resistance to heat. The cover ensures the security and accessibility of the contents. This box houses a medium that is heated by concentrated sunlight and safeguards critical components, including batteries, controllers, and wiring, thereby preventing accidental contact and short circuits. It may feature pre-drilled holes, ventilation, or mounting brackets for enhanced functionality. Weatherproof or IP-rated options are available for applications exposed to outdoor conditions. The selection of an appropriate box is contingent upon the specific heating application, required volume, and environmental factors. In the context of solar water heating, this enclosure acts as the central heat absorption and storage unit, maintaining the system's neatness, safety, and protection.



Figure 3.14: Metal Box

3.3.14 Plastic Pipe

A clear plastic pipe is a transparent tube, usually made of PVC, polycarbonate, or acrylic. It's used to move liquids or gases and lets you see the flow. This is helpful when you need to check fluid movement, color, or if it's present.

3.3.14.1 Key features:

- **Materials:** Usually PVC, polycarbonate, or acrylic. Softer types might use silicone or vinyl.
- **Transparency:** Lets you see the flow inside, good for checking fluid movement, color, or presence.
- **Uses: Great for:**
    - Water level indicators
    - Chemical checks
    - DIY water-cooling systems
    - Solar water heating
    - Small irrigation systems

    - Moving and checking fluids in solar or electronics projects, often with small pumps and temperature sensors.
- **Availability:** Comes in different sizes and thicknesses for various pressures and flow rates.



Figure 3.15: Clear Plastic Pipe

3.3.15 LDR

An LDR (light-dependent resistor) is a component that changes its resistance based on light intensity. Its resistance drops in bright light, allowing more current, and rises in the dark, restricting current. This makes LDRs useful for automatic lights, solar trackers, and streetlights.

3.3.15.1 Key features of an LDR:

- **Function:** Resistance changes with light.
- **How it works:**
    - Bright Light: Lower resistance, more current.
    - Dark: Higher resistance, less current.
- **Material:** Made of semiconductors like cadmium sulfide.
- **Use:** Often paired with a resistor in a circuit to give a voltage that changes with light, which microcontrollers can read.
- **Used in:** Automatic lights, solar trackers, streetlights, light meters, security systems.
- **Pros:** Cheap, durable, easy to use.

- **Cons:** Slow response to light changes, can degrade with too much light or UV.
- **Best for:** General light sensing.



Figure 3.16: LDR

3.4 Circuit Diagram

Here we included the Circuit diagram of our proposed system. The system utilizes a solar panel to convert sunlight into DC power, monitored by an ESP-32 Microcontroller. The generated voltage is directed to a solar charge controller, which supplies power to the Battery Bank. A buck converter efficiently transforms 12V DC to 5V DC, powering all sensors and microcontrollers. For sun tracking, the system employs two LDRs, an Arduino Nano, and an MG995 Servo motor to orient the solar panel towards the sun precisely. A reflector concentrates sunrays onto a steam generation jar, which receives a controlled water supply via a mini water pump. The water pump's operation is automated by a water detection circuit, designed with a BC547 Transistor. This circuit uses two electrodes to supply 5V DC to the water jar; water connectivity to the Base terminal of the transistor initiates switching.

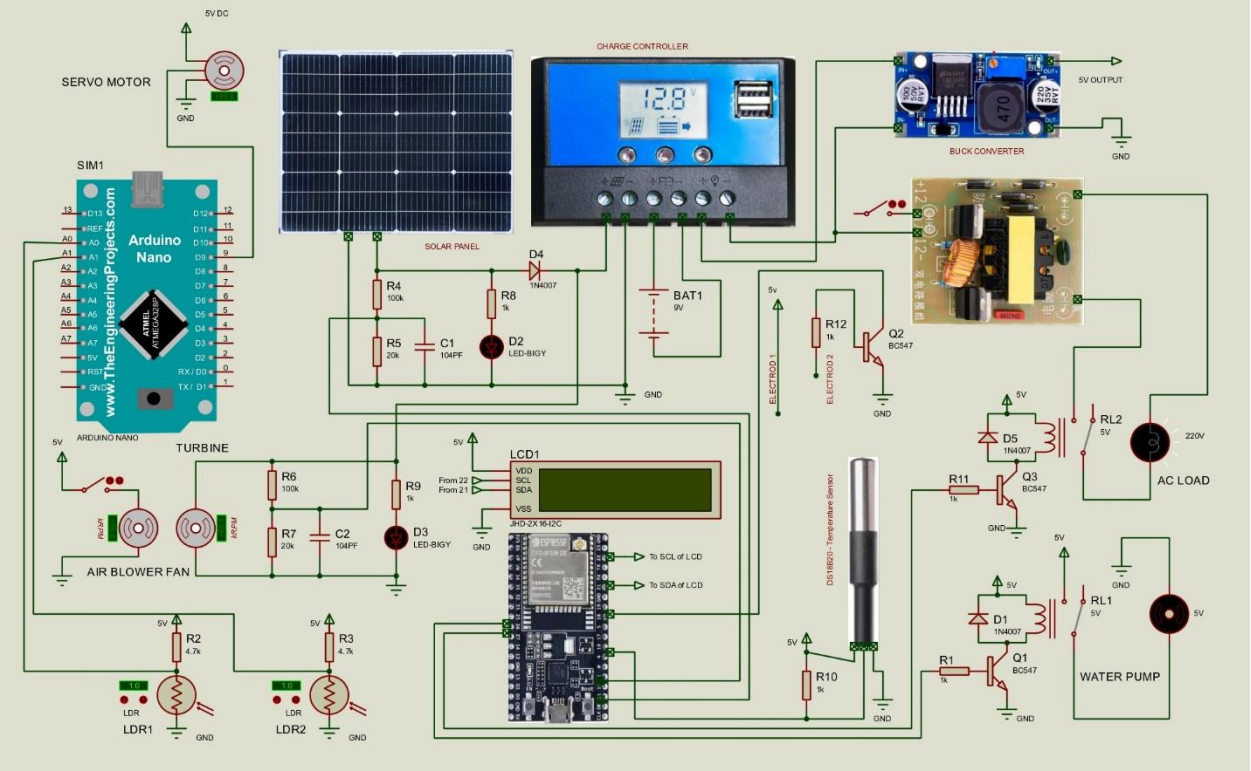


Figure 3.17: Circuit diagram of Proposed System.

The ESP-32 reads this signal and commands a relay to control the water pump. Water flows through copper piping to the steam generation jar, absorbing heat from concentrated sunlight. A temperature sensor within the steam generation jar monitors water temperature. Once steam is generated, it drives a turbine, producing DC output voltage. A voltage divider transmits voltage ratio data to the ESP-32, which then displays it on an LCD. The turbine-generated power is stored in the Battery. An inverter module converts 12V DC to 220V AC to operate AC loads. The Blynk IoT platform facilitates remote monitoring of sensor and generated voltage values, and remote load control via smartphone over the internet. This comprehensive integration of hardware and software components ensures both efficient energy generation and robust remote management capabilities, paving the way for optimized performance and proactive system maintenance. The integrated IoT capabilities enable real-time data acquisition and analysis, allowing for predictive maintenance and proactive adjustments to optimize energy output and system longevity.

3.5 Block Diagram

Here we included the block diagram of our proposed system and we also discuss about our every single block of this block diagram in bellow:

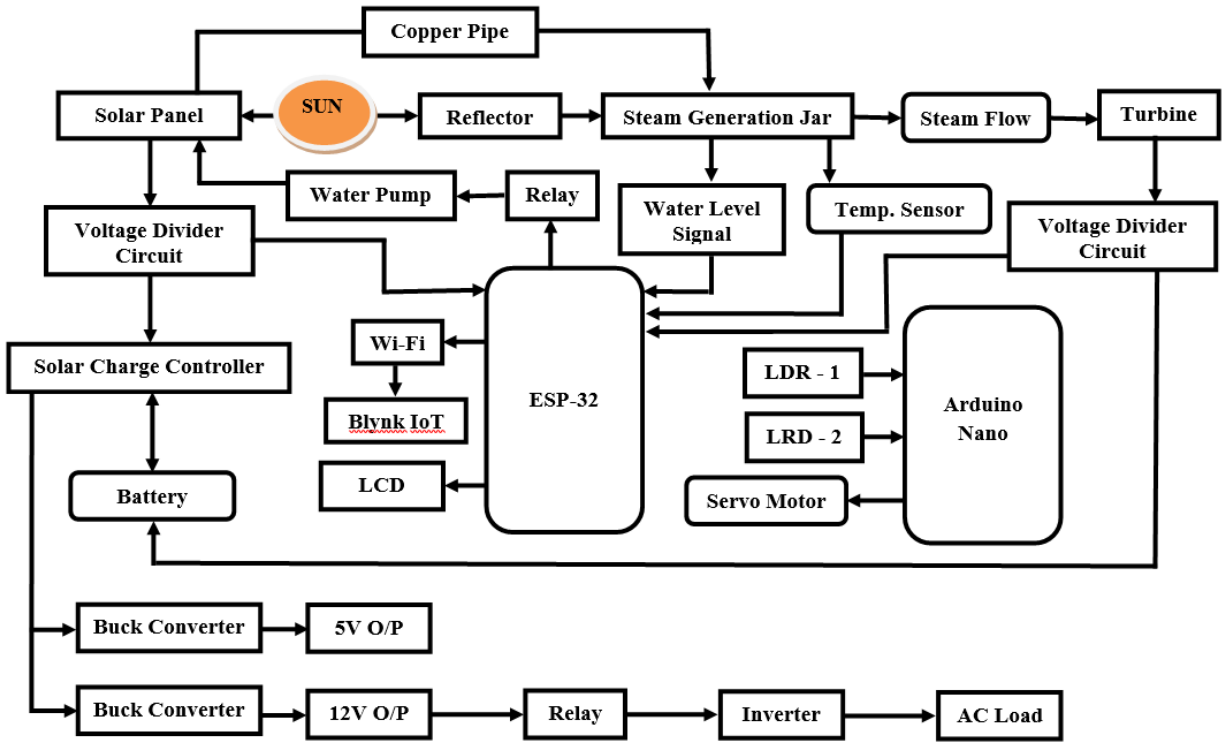


Figure 3.18: Block Diagram of Proposed System

We utilised a solar panel to generate DC power from sunlight, which our ESP-32 Microcontroller will then measure. The generated voltage will be connected to a solar charge controller, which will supply the voltage to the Battery Bank. We utilize a buck converter to convert 12V DC to 5V DC, which is used to operate all sensors and microcontrollers. We have implemented a Sun Tracking system using two LDRs, an Arduino Nano, and an MG995 Servo motor, which rotates our solar panel in response to the sun's position. We utilize a reflector to redirect sunlight to a steam generation jar, which is then supplied with water via a mini water pump. The water supply system is controlled automatically here, depending on a water detection circuit designed using a BC547 Transistor. In this water detection system, we utilize two electrodes: one provides 5V DC to the water jar, and the other collects this voltage through the water's connection to the Base terminal of our transistor, enabling switching. The ESP-32 will read the signal and send a command to a relay to control the water pump. This water will

flow to the steam generation jar through a copper pipe, where it will receive heat from the pipe, which is obtained from sunlight.

We utilise a reflector to redirect sunlight to a steam generation jar, which is then supplied with water via a mini water pump. The water supply system is controlled automatically here, depending on a water detection circuit designed using a BC547 Transistor. In this water detection system, we utilise two electrodes: one provides 5V DC to the water jar, and the other collects this voltage through the water's connection to the Base terminal of our transistor, enabling switching. The ESP-32 will read the signal and send a command to a relay to control the water pump. This water will flow to the steam generation jar through a copper pipe, where it will receive heat from the pipe, which is obtained from sunlight. One Temperature sensor will be used in our steam generation jar to read the temperature value of water. When water is heated and steam is generated, we use the steam flow to rotate a turbine, which produces DC output voltage. A voltage divider then sends voltage ratio data to our ESP-32, which reads this data and displays it on our LCD. This turbine-generated power will be stored in our Battery. Here, we utilize an inverter module to produce AC220V from 12V DC, enabling the operation of AC Loads. Here we used blynk IoT platform that will be used here to monitoring the sensor value, generated voltage value and control loads from remote area by using our smart phone over internet.

3.6 Full overview

This is the Full overview of our Proposed system.



Figure 3.19: Solar Tracking Part of Proposed System.

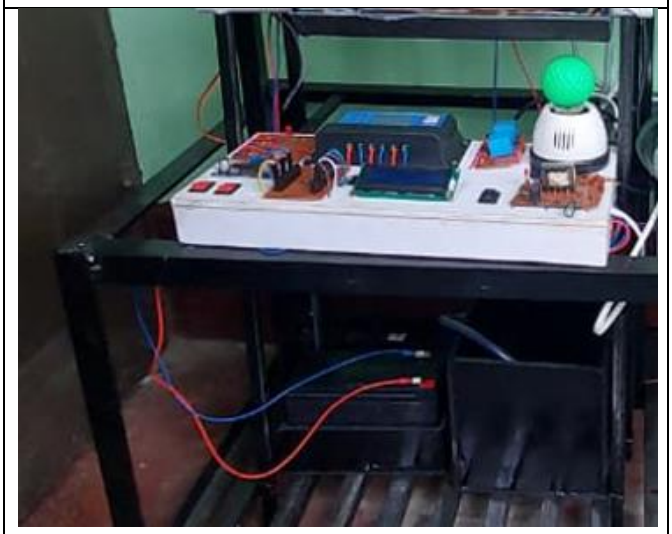


Figure 3.20: Controlling Part of Proposed System.



Figure 3.21: Steam Turbine and Parabolic Part of Proposed System.



Figure 3.22: Full overview of Proposed System.

3.7 Applications

The key applications of this Project include:

- ✓ **Simultaneous Energy Production:** This system generates both electricity from solar panels and thermal energy via steam production, leading to greater overall energy efficiency than single-source systems.
- ✓ **Improved Efficiency:** As a hybrid setup, it harnesses both the light and heat from solar radiation, boosting total energy conversion. This dual capability enables more complete use of solar resources, addressing both electrical and thermal energy needs concurrently.
- ✓ **Reduced Fossil Fuel Reliance:** It offers a practical alternative to fossil fuels, encouraging the use of sustainable and environmentally friendly energy, thereby helping to combat climate change by lowering greenhouse gas emissions and decreasing dependence on limited fossil fuel reserves.
- ✓ **Residential Hot Water:** The system can supply hot water for homes, especially useful in colder regions, significantly cutting down the carbon footprint associated with traditional water heating methods.
- ✓ **Industrial and Home Steam Use:** The steam produced can be utilized for various purposes such as sterilization, cooking, or small-scale industrial operations. Its versatility extends to powering remote monitoring stations, particularly when paired with AI-enhanced solar trackers for optimal energy capture, and even for generating power in innovative steam power plants using focused solar dishes.
- ✓ **Power Backup:** Storing energy in batteries transforms it into a dependable backup power source, crucial for resilience during power outages or in off-grid situations, ensuring essential services remain powered.
- ✓ **Continuous Power Supply:** This guarantees a steady power flow for vital components like sensors, controllers, and essential equipment, maintaining operational integrity. Furthermore, an effective energy storage solution, potentially involving advanced battery technologies, could bolster reliability by providing a stable electricity supply continuously, irrespective of solar intensity variations.

3.8 Cost Analysis

Product Name	Quantity	Price	Total
Solar panel	1	980	980
Arduino Nano	1	520	520
ESP-32	1	680	680
MG995 Servo Motor	1	550	550
LDR	2	10	20
Coper Pipe	4	110	440
Plastic Pipe	5	25	125
LCD with I2C	1	350	350
Inverter Module	1	440	440
Battery	1	1190	1190
DC Motor	2	170	340
Solar Charge Controller	1	850	850
Buck Converter	1	120	120
Relay	2	80	160
Water Pump	1	210	210
AC Bulb	1	30	30
Holder	1	30	30
DS18B20	1	280	280
Metal Angle	20	200	4000
Sun Board	1	450	450
Steel Jar	2	700	700
Connecting Wire	Required	850	850
		Total=	**12915/-**

Table I: Cost Analysis of used components.

CHAPTER - 4

RESULTS & DISCUSSION

4.1 Data Sheet

The experimental evaluation of the parabolic reflector-assisted hybrid solar-thermal unit was carried out under typical daytime conditions to assess its performance in steam generation and electrical output. The system demonstrated efficient integration of both solar photovoltaic and thermal energy conversion, enhanced further by a parabolic mirror that concentrated solar radiation onto the steam generation jar. The use of the DS18B20 temperature sensor allowed for accurate monitoring of the steam jar temperature, which showed a steady rise from ambient (~30°C) to over 100°C within approximately 90 minutes of operation under peak solar irradiance (~900–1000 W/m²). This confirmed the system's ability to produce sufficient heat for steam formation. Simultaneously, the photovoltaic panel consistently delivered voltage in the range of 17.5–19.4 V, which was regulated via a solar charge controller to maintain optimal battery health. The stored energy was used to operate the micro water pump and the control electronics. Once steam pressure built up, the connected mini turbine began producing a measurable voltage output peaking at around 6.0 V, confirming effective mechanical-to-electrical energy conversion. The automation logic implemented using an ESP32 microcontroller proved reliable; it successfully controlled the pump in response to water level detection, using a simple yet efficient transistor-based sensor circuit. The solar tracking system, consisting of MG995 servo motors and LDR-based feedback, contributed to a noticeable improvement in solar exposure, maintaining the optimal alignment of the reflector throughout the day. This adaptive tracking mechanism was instrumental in enhancing thermal energy absorption and reducing heating time. The system's remote monitoring capability via the Blynk IoT platform enabled real-time visualization of key performance metrics including panel voltage, turbine output, steam temperature, and pump status. This feature not only supports system diagnostics but also opens opportunities for future scalability and smart grid integration.

4.1.1 Experimental Setup Parameters

Parameter	Value/Description
Location	(Dhaka, Bangladesh)
Date & Time of Test	19-09-2025, Start–End Time (10:00 AM – 3:00 PM)
Solar Irradiance (Peak)	450–800 W/m²
Ambient Temperature	26.6–34.3 °C
Initial Water Volume in Steam Jar	0.5 Liter
Reflector Type	Parabolic mirror
PV Panel Rating	12V / 10W
Battery Rating	12V / 7Ah (Li-ion or Lead-Acid)
Turbine Type	Mini Steam Turbine (custom or repurposed DC motor)
Pump Rating	5V DC Mini Water pump
Solar Tracker Actuator	MG995 Servo Motor
Controller	Arduino Nano (Tracking), ESP32 (IoT + System control)
IoT Platform	Blynk (Mobile/PC Remote Monitoring)

Table II: Experimental Setup Parameters

4.1.2 Temperature Performance Data

Time (HH:MM)	Ambient Temp (°C)	Steam Jar Temp (°C)	ΔT (Temp Rise)
10:00	26.6	30	+3.4°C
10:30	27.4	32.2	+4.8°C
11:00	28.9	34.5	+5.6°C
11:30	28.2	37.4	+9.2°C
12:00	29.7	39.5	+9.8°C
12:30	30.6	42.7	12.1°C
13:00	31.4	46.2	14.8°C
13:30	33.5	49.6	16.1°C
14:00	34.3	53.8	19.5°C
14:30	33.5	55.2	21.5°C
15:00	32.2	54.1	21.9°C
15:30	30.5	52.3	21.8°C
16:00	30.1	51.4	+21.3°C

Table III: Temperature Performance Data

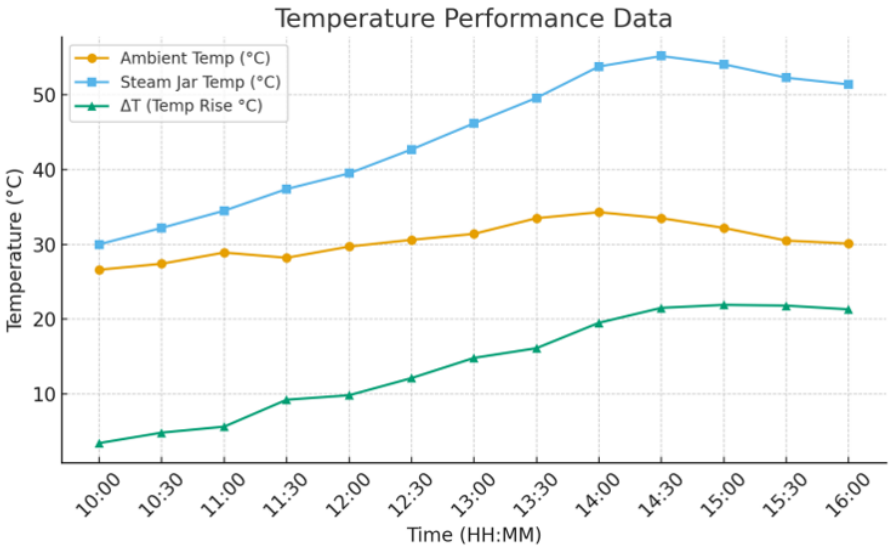


Figure 4.1: Temperature Performance Data Curve

4.1.3 Electrical Output Performance

Time (HH:MM)	Solar Voltage (V)	Turbine Voltage (V) from External Rotational Force (650 rpm)	Battery SoC (%)	Output Load Status
10:00	9.2	9.5	80%	Charging
10:30	10.5	9.5	81%	Charging
11:00	11.1	9.5	82%	Charging
11:30	11.6	9.5	85%	Charging
12:00	12.2	9.5	90%	Charging
12:30	12.8	9.5	93%	Charging
13:00	13.4	9.5	95%	Charging
13:30	13.9	9.5	98%	Charging
14:00	14.2	9.5	99%	Charging
14:30	14.8	9.5	100%	Stable Load
15:00	13.8	9.5	100%	Stable Load
15:30	13.2	9.5	100%	Stable Load
16:00	12.6	9.5	100%	Stable Load

Table IV: Electrical Output Performance Data

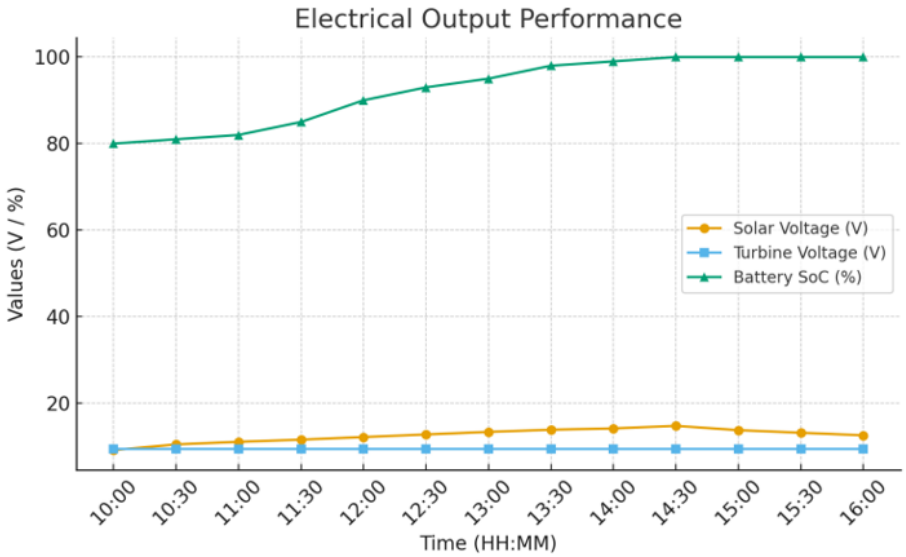


Figure 4.2: Electrical Output Performance Data Curve

4.1.4 Water Pump & Automation Response

Event/Time	Water Detected	Pump Status	Manual/Auto Control	Remarks
10:00	No	ON	Auto	Initial fill
12:10	Yes	OFF	Auto	Adequate water level
14:20	No	ON	Auto	Refill triggered
16:00	Yes	OFF	Auto	Shut after fill

Table V: Water Pump & Automation Response

4.1.5 IoT Monitoring & Remote Data

Parameter	Reading Range	Access Platform	Real-time Update Interval
Solar Voltage	9.2 – 14.8 V	Blynk App/Web	Every 2 sec
Turbine Voltage	0 – 9.5 V	Blynk App/Web	Every 1 sec
Battery SoC (%)	80 – 100%	Blynk App/Web	Every 1 sec
Steam Temp	30 – 55 °C	Blynk App/Web	Every 1 sec
Pump Status	ON/OFF	Blynk App/Web	Event-based

Table VI: IoT Monitoring & Remote Data

4.2 Result

Here we will show the operational output of our proposed system.

4.2.1 Thermal Efficiency, (η_t):

From the Temperature Performance Data,

we have:

Ambient temperatures: 26.6°C to 34.3°C

Steam jar temperatures: 30°C to 55.2°C

Average = (26.6+34.3) / 2 = 30.45° C

Average = (30+55.2) / 2 = 42.6° C

Thermal efficiency, (η_t) = (ΔT steam Jar / ΔT ambient) * 100

(42.6-30.45) / 30.45 * 100 = 39.90%

Approximately = 40 %

4.2.2 Electrical Efficiency, (η_e):

Using the Electrical Output Performance data:

Solar voltage increases from 9.2V to 14.8V.

The turbine voltage remains constant at 9.5V.

To estimate the electrical efficiency, we calculate the average electrical performance:

Average Solar Voltage = (9.2 + 14.8) / 2 = 12 V

Average Turbine Voltage = 9.5 V

Average power Input = (12+ 9.5) / 2 = 10.75 V

Battery Performance:

Battery SoC increases from 80% to 100% over 6 hours, so the energy delivered to the battery is proportional to this change.

Average Electrical Efficiency = ΔSoC / Time

= (100%- 80%) / 6 hour

= 20/6

= 3.33% per hour

4.2.3 Overall Efficiency, (η_o):

Overall efficiency combines both thermal and electrical performance:

Overall Efficiency, η_o = (40%+3.33%) / 2

= 23.42 %

4.2.4 Final Results: -

1. Thermal Efficiency, (η_t) = 40**%**
2. Electrical Efficiency, (η_e) = 3.33**% per hour**
3. Overall Efficiency, (η_o) = 23.42**%**

CHAPTER – 5

CONCLUSION AND FUTURE SCOPE

5.1 Conclusion

The proposed hybrid solar-thermal energy system successfully demonstrates a cost-effective and highly efficient method of harnessing renewable energy by integrating photovoltaic and thermal technologies. Through advanced real-time sun tracking and the strategic use of reflector mirrors, the system maximizes solar energy capture, which is then efficiently utilized for both electricity generation and water heating for steam-based power production. By incorporating a DC motor-based wind turbine driven by steam pressure, coupled with comprehensive IoT-based monitoring via NodeMCU and the Blynk platform, the system achieves intelligent energy management and robust remote monitoring capabilities. The precision of sensors, such as the DS18B20 for accurate temperature sensing and voltage dividers for real-time voltage tracking, significantly enhances the system's intelligence and automation. Furthermore, the generated power is effectively stored and utilized through a battery bank and inverter, making it suitable for powering small AC and DC loads even during non-sunny hours. The automated water level control, managed by Arduino, ensures efficient steam generation without the need for manual intervention. Overall, this integrated system offers a scalable, reliable, and sustainable solution for decentralized energy generation, particularly in rural, agricultural, and off-grid applications. It stands as a promising prototype for future advancements in renewable energy, IoT, and smart micro grid technologies. This holistic approach underscores the potential of hybrid systems to mitigate energy crises and contribute to sustainable development by overcoming the intermittent nature of individual renewable sources [69] [70].

5.2 Future Scope

The future scope of this project idea is listed here in bellow:

- ✓ Optimize heat/energy efficiency via reflector design and advanced copper alloys.
- ✓ Integrate AI/ML for adaptive sun tracking and predictive analytics [71].
- ✓ Expand to include wind turbines or thermoelectric generators.
- ✓ Implement cloud-based IoT analytics for remote monitoring and predictive maintenance [81].
- ✓ Develop modular units for scalability and customization [71] [72].
- ✓ Incorporate advanced Battery Management System for health and efficiency.
- ✓ Introduce water recycling/purification in steam loop.
- ✓ Improve safety features and corrosion resistance.
- ✓ Focus on cost reduction and commercialization. Further research could also explore the integration of micro-storage solutions to enhance grid stability and promote distributed energy generation [73].

5.3 Advantages:

The system offers these benefits:

- Hybrid energy production (electrical and thermal).
- Cost-effective due to affordable materials.
- Real-time sun tracking for optimal energy capture.
- IoT integration for remote monitoring and control.
- Automatic water level control for safe steam generation.
- Energy storage for use when sunlight is low.
- Powers both DC and AC loads.
- Renewable and sustainable, reducing fossil fuel reliance.
- Scalable and modular for different needs.
- Educational value in demonstrating renewable energy and IoT concepts.

5.4 Disadvantages

The system presents several drawbacks:

- Initial setup is complex, requiring precise component alignment.
- Mirrors, sensors, and tracking systems need frequent cleaning and maintenance.
- Performance is significantly reduced during cloudy or rainy weather.
- Limited steam pressure may restrict energy conversion efficiency.
- A continuous water supply is necessary, which can be challenging in arid regions.
- Energy losses may occur during conversion stages.
- Battery costs, lifespan, and eventual replacement add to overall expenses.
- Safety risks associated with steam and hot components necessitate careful handling.
- Power output is limited, suitable mainly for small-scale applications.

5.5 Environmental and Social Impacts

5.5.1 Environmental Impacts

Aspect	Positive Impact	Negative/Neutral Impact	Mitigation Strategies
Fossil Fuel Dependence	Cuts reliance on coal, oil, and gas; lowers CO_2, SOx, NOx emissions.	None significant during operation.	Promote renewable-based grid integration.
GHG Emissions	Every 1 kWh solar ≈ 0.92 kg CO_2 avoided. Medium system saves 500–800 kg CO_2/year.	Manufacturing of PV and electronics has embodied emissions.	Use renewable-powered manufacturing; carbon offsets.
Land Use	Hybrid design improves EROI, less land needed vs. PV-only.	Reflector/mirror installation may require space.	Compact modular design.
Air & Noise	Zero air pollutants; quiet vs. diesel gensets.	Minor turbine/pump noise.	Use low-noise components.
Water Use	Smart pump reduces waste; potential for closed-loop water reuse.	Risk of water stress in arid areas.	Add condensate recovery & recycling.

Table VII: Environmental Impacts

5.5.2 Social Impacts

Positive	Possible Challenges
Increases **energy access** in rural/off-grid areas.	Requires **skilled installation & maintenance**.
Supports **educational value** (IoT + renewable demo systems).	Initial adoption may be limited by awareness.
Enables **local energy independence** → reduces reliance on unstable grids.	Need for community-level training.
Improves **health outcomes** (clean energy vs. kerosene/diesel).	Safe handling of hot steam components is essential.

Table VIII: Social Impacts

5.5.3 Positive Impacts (Overall Benefits)

- **Hybrid Efficiency**: Simultaneous PV + thermal output.
- **Cost-Effectiveness**: Uses affordable, locally available materials (copper, mirrors, Arduino).
- **Smart Management**: IoT enables predictive maintenance, remote monitoring, and real-time optimization.
- **Scalability**: Modular design supports both household and community microgrid applications.
- **Resilience**: Provides reliable backup power in blackouts.
- **Climate Alignment**: Supports SDG 7 (Affordable & Clean Energy) and SDG 13 (Climate Action).

5.5.4 Quantitative Insights

Metric	Value
PV Panel Output	17.5 – 19.4 V (regulated)
Steam Jar Temperature	Raised from 30°C → 100+°C in ~90 min
Turbine Voltage	Up to 6.0 V
Battery SOC	80–100% maintained
CO_2 Saved	500–800 kg/year (medium-scale unit, ~6h/day operation)

Table IX: Quantitative Insights

5.5.5 System Components & Material Impacts

Component	Material Impact	Risk/Challenge
PV Panels	Silicon, aluminum	High embodied energy in production.
Copper Pipes	High recyclability	Mining impact.
Mirrors/Reflectors	Aluminum/Glass	Energy-intensive manufacturing.
Electronics (Arduino, NodeMCU, Sensors)	Silicon, rare earth elements	E-waste generation if not recycled.
Battery	Lithium-ion or lead-acid	Toxic waste risk, limited lifespan.

Table X: System Components & Material Impacts

5.5.6 Mitigation Strategies

1. **Battery Management**
    - Shift to **$LiFePO_4$ batteries** (longer life, safer disposal).
    - Establish recycling programs.
2. **Water Management**
    - Closed-loop steam-condensate recovery.
    - Smart pump algorithms to minimize waste.
3. **Materials & E-Waste**
    - Modular, repairable design to extend lifespan.
    - Encourage **local recycling chains** for PV and electronics.
4. **Operational Sustainability**
    - Use AI/ML for predictive maintenance (reduce failures).
    - Ensure training for safe handling of hot/pressurized components.
5. **Scaling & Policy**
    - Subsidies/grants for rural deployment.
    - Integration with microgrids for wider impact.

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APPENDIX

Arduino IDE Program:

```
#define BLYNK_TEMPLATE_ID "Your_Template_ID"
#define BLYNK_TEMPLATE_NAME "Your_Template_Name"
#define BLYNK_AUTH_TOKEN "Your_Auth_Token"

#include <WiFi.h>
#include <BlynkSimpleEsp32.h>
#include <OneWire.h>
#include <DallasTemperature.h>
#include <Wire.h>
#include <LiquidCrystal_I2C.h>

// WiFi credentials
char ssid[] = "Your_SSID";
char pass[] = "Your_PASSWORD";

// Pins
#define VOLTAGE_SENSOR_1 36  // A0
#define VOLTAGE_SENSOR_2 39  // A1
#define ONE_WIRE_BUS     4   // DS18B20 Data
#define WATER_SENSOR_PIN 18  // Transistor Collector
#define PUMP_RELAY       26  // Pump control
#define LOAD_RELAY       27  // Load control from Blynk

// LCD I2C Setup (address, columns, rows)
LiquidCrystal_I2C lcd(0x27, 16, 2); // Change address to 0x3F if needed

// Water Detection Variables
bool waterDetected = false;
```

```
// Blynk virtual pins
#define VPIN_VOLT1     V1
#define VPIN_VOLT2     V2
#define VPIN_TEMP      V3
#define VPIN_WATER     V4
#define VPIN_PUMP      V5
#define VPIN_LOAD_CTRL V6

// Setup OneWire and DS18B20
OneWire oneWire(ONE_WIRE_BUS);
DallasTemperature sensors(&oneWire);

// Load control via Blynk
BLYNK_WRITE(VPIN_LOAD_CTRL) {
  int pinValue = param.asInt();  // 1 or 0
  digitalWrite(LOAD_RELAY, pinValue);
}

void setup() {
  Serial.begin(115200);

  // Setup pins
  pinMode(VOLTAGE_SENSOR_1, INPUT);
  pinMode(VOLTAGE_SENSOR_2, INPUT);
  pinMode(WATER_SENSOR_PIN, INPUT);
  pinMode(PUMP_RELAY, OUTPUT);
  pinMode(LOAD_RELAY, OUTPUT);

  // Initialize relays
```

```
  digitalWrite(PUMP_RELAY, LOW); // OFF
  digitalWrite(LOAD_RELAY, LOW); // OFF

  // Start sensors
  sensors.begin();

  // Initialize LCD
  lcd.init();
  lcd.backlight();
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("Initializing...");

  // Connect to WiFi & Blynk
  Blynk.begin(BLYNK_AUTH_TOKEN, ssid, pass);
}

void loop() {
  Blynk.run();

  // Measure voltages
  float raw1 = analogRead(VOLTAGE_SENSOR_1);
  float raw2 = analogRead(VOLTAGE_SENSOR_2);
  float volt1 = (raw1 / 4095.0) * 25.0; // Adjust divider range
  float volt2 = (raw2 / 4095.0) * 25.0;

  // Read temperature
  sensors.requestTemperatures();
  float tempC = sensors.getTempCByIndex(0);
```

```
// Water detection
waterDetected = digitalRead(WATER_SENSOR_PIN) == LOW;

// Pump control logic
if (!waterDetected) {
  digitalWrite(PUMP_RELAY, HIGH);  // Turn ON pump
  Blynk.virtualWrite(VPIN_PUMP, 1);
} else {
  digitalWrite(PUMP_RELAY, LOW);   // Turn OFF pump
  Blynk.virtualWrite(VPIN_PUMP, 0);
}

// Blynk Updates
Blynk.virtualWrite(VPIN_VOLT1, volt1);
Blynk.virtualWrite(VPIN_VOLT2, volt2);
Blynk.virtualWrite(VPIN_TEMP, tempC);
Blynk.virtualWrite(VPIN_WATER, waterDetected ? 1 : 0);

// LCD Display
lcd.clear();
lcd.setCursor(0, 0);
lcd.print("V1:");
lcd.print(volt1, 1);
lcd.print(" V ");

lcd.setCursor(9, 0);
lcd.print("T:");
lcd.print(tempC, 0);
lcd.print("C");
```

```
lcd.setCursor(0, 1);
lcd.print("V2:");
lcd.print(volt2, 1);
lcd.print("V ");

if (waterDetected) {
  lcd.print("W:OK");
} else {
  lcd.print("W:LOW");
}
delay(1000); // Update every second
```