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Integrating Micro-Hydro and Solar PV in Rainwater Harvesting: A Hybrid Generation Approach

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ABSTRACT

As the scarcity of water worsens and the frequency of severe weather increases, the efficient harvesting of rainwater becomes more critical. Despite its potential to conserve water and mitigate flooding, the integration of rainwater harvesting with solar PV and micro-hydro technologies remains underutilized in renewable energy production. A significant barrier to widespread adoption is the challenge of accurately quantifying energy generation and optimizing management practices. This project aims to address these issues by proposing a method to develop a rainwater harvesting system that integrates solar PV and micro-hydro technologies. The primary objective is to evaluate the practical performance of this hybrid system in driving applications such as irrigation and sanitation. The findings demonstrate that the integrated system outperforms conventional methods, suggesting its effectiveness in rainwater utilization as a renewable energy resource.

1. Introduction

Rainwater harvesting is a vital practice that conserves clean water during dry seasons and helps manage flooding during heavy rainfall events. With the increasing global population, groundwater depletion and water scarcity have become significant concerns. The collected rainwater can be utilized immediately for irrigation or stored for future use in various reservoirs. This traditional technique, crucial for arid regions, is gaining prominence worldwide as population growth strains conventional energy sources. Research explores renewable energy options such as solar panels on buildings and closed-loop rainwater harvesting systems.

Floods, often triggered by excessive precipitation, pose serious challenges, causing damage and contamination. While rainwater harvesting mitigates runoff, it's essential to address flooding through improved drainage systems and green infrastructure. Yet, the interplay between rainwater collection

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and flooding warrants attention, particularly in regions with intense rainfall. By capturing and storing rainwater, these systems alleviate pressure on local water resources.

To maximize sustainability, it's crucial to integrate rainwater harvesting with other renewable energy sources like solar and micro-hydro power. While direct conversion of rainwater into electricity remains elusive, leveraging existing renewable technologies can yield significant benefits. This paper aims to evaluate the energy output of a hybrid micro-hydro and solar PV system integrated into a rainwater collection setup. The objective is to develop and assess a system that combines micro-hydro and solar technologies within small-scale rainwater collection systems. Emphasis will be placed on energy consumption for tasks like irrigation and toilet flushing, providing valuable insights into sustainable energy usage.

2. Literature Review

Freshwater scarcity has arisen as a significant concern in sustainable development, as indicated by a review of past research. Population expansion, improved quality of life, changes in spending habits, and more agriculture irrigation have all been highlighted as important drivers of rising freshwater demand. The primary cause of global water scarcity is an imbalance between freshwater demand and supply [1]. The most major impact of a rising population on human civilization would most likely be the rapid loss of groundwater, drinking water, and usable freshwater [2].

Rainwater harvesting is a viable option that captures and uses rainwater that would otherwise go to waste. Water usage can be divided into two categories: consumerist and non-consumptive. Consumption occurs when more water leaves the system than is returned, whereas non-consumptive use results in low or no losses [3]. However, establishing efficient rainwater harvesting systems presents numerous problems due to limited infrastructure, financial restrictions, a lack of knowledge, and educational resources.

2.1 Rainwater Harvesting System

Traditional rainwater harvesting systems (RWHS) have evolved over millennia in response to irregular rainfall patterns, with mystical underpinnings profoundly established in indigenous cultures. Rediscovered now, these past approaches provide viable solutions to water challenges and serve as a paradigm for long-term water management. Traditional house RWHS, which are popular in disadvantaged rural areas, can provide potable water in arid climates. To evaluate their involvement in sustainable water management, a study of the linkages between natural and human behaviours, social and economic systems, and sustainability concerns is required [4]. Figure 1 depicts a typical rainwater harvesting system in frequent use.

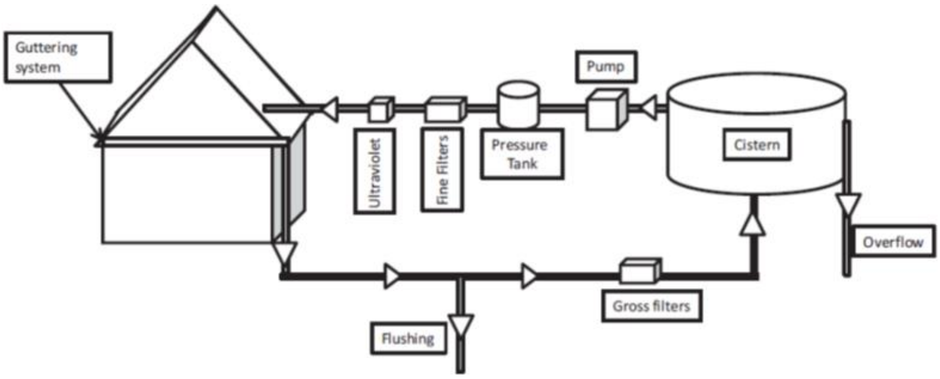

Fig. 1. A Typical RWH system [5]

Rainwater harvesting systems with distributed control are adaptable and fulfil a variety of functions. Modern rain harvesting systems reuse rainwater for irrigation, floor cleaning, and toilet flushing. They also generate electricity by combining the energy released by the water volume in the conduction system with the kinetic energy at the flow outlet. The Pumps as Turbines (PaT) concept proposes leveraging current hydraulic systems for a variety of applications [6].

2.1.1 Rainwater harvesting system in Malaysia

Despite substantial rainwater collection prospects in Malaysia for agriculture and industry, poor community acceptance and long-term financial investment prevent widespread adoption of RWHS as a viable water resource substitution. Melaka City Council (MBMB), in response to a demand from the National Council for Local Government (MNKT), has ordered a "rainwater collection and reuse system" for semi-detached residences, bungalows, independent buildings, and factories [7]. Rainwater collected in Melaka is used for a variety of reasons, including ordinary cleaning, toilet flushing, and landscaping. To gain construction plan approval, consultants must follow MBMB standards, which include rainwater tank positioning, Rainwater Collection System (RCS) element incorporation, appropriate roof design, and optimal trough maintenance. MBMB stresses the benefits of RCS, which include water supply during crises, a 25-30% water savings, and lower water bills. Figure 2 shows the RWHS enforcement brochure or poster in Malaysia, specifically Melaka.

Fig. 2. RWHS Enforcement in Melaka, Malaysia [7]

2.2 Renewable Energy Generation from RWHS

Rooftop rainwater harvesting (RWH), which collects rainwater from roof catchments and stores it in reservoirs, provides a diverse alternative. This gathered water can be utilized to generate electricity using turbines or stored in underground reservoirs to suit home requirements. The basic purpose of rooftop rainwater collection is to accumulate large amounts for future use [8]. Rainwater collection devices such as hydropower systems, piezoelectric panels, and vortex turbines are examples of sustainable energy sources.

The flow of rainfall can be harnessed to generate hydropower, a type of renewable energy. Micro-hydropower systems typically consist of a turbine, generator, and control system [9]. Rainwater collection systems in general have the potential to act as a renewable energy source, notably hydropower. Furthermore, the combination of hydropower and solar energy generation can boost overall renewable energy output [10,11]. Combining several sources presents a great opportunity for producing renewable energy through synergistic integration.

According to previous research, the process of generating electricity using micro hydro entails harnessing the power of flowing water through a small-scale hydroelectric system [12,13]. Micro hydro is classified into two types: internal turbines and external turbines. Its primary application is to give power to rural or distant locations that are not connected to the national grid.

A concept supports installing efficient micro-hydro turbine systems on downspouts of homes and businesses to gather and utilize rainwater's untapped energy potential, efficiently powering gadgets [14]. The identified potential for power extraction is directly proportional to the number of turbines within the pipeline. In comparison to other non-renewable energy producing systems, this technology is easier and less expensive to put up and use. However, efforts to commercialize it necessitate additional research to address existing limitations [15].

Alternatively, a study on renewable energy harvesting identifies piezoelectric components as the best option for low-power supply. Raindrops can work as energy harvesters, transforming mechanical energy into electricity when they contact a piezoelectric sensor. This gathered energy can be used to power home gadgets such as LED lighting and fans. Even amid severe downpour, the piezoelectric sensor values vary with floor altitude [16,17]. The primary notion is to transform mechanical energy, such as vibration or tension, into electricity. Piezoelectric plates effectively convert the kinetic energy of raindrops into electrical energy. A comparative study of piezoelectric materials investigates their potential as a water droplet source of energy for low-power electronic devices. The crystalline structure of piezoelectric materials determines their ability to transfer electrical energy to mechanical energy and vice versa [18].

2.2.1 RWHS concept for electricity generation

In a study conducted at Sekolah Menengah Kebangsaan Iskandar Syah (SMKIS) in Melaka, a rainwater harvesting (RWH) system was implemented to enhance landscape sustainability [19]. The concept and proposed RWH system are depicted in Figure 3 and Figure 4 respectively. The turbine generated 26.6 watts, which powered a scrolling message board in Taman Herba. Predictions for generated power were based on hill height, and elements such as pipe diameter and type were assessed to ensure optimal power output. Using marketed pipe diameters helped to reduce the overall cost of the RWH system.

Because of the generation of hazardous gases like sulfur dioxide, carbon monoxide, and nitrogen dioxide, which causes water pH to rise through disintegration, Rani *et al.,* [20] stresses rainwater harvesting quality control. To measure watercolor and turbidity levels, the author uses an IoT application that includes an LDR sensor and a turbidity sensor. Simultaneously, Verma *et al.,* [21] focuses on smart water management with IoT in rainwater collection systems. The proposed approach seeks to help people facing water-related issues throughout the summer and rainy seasons by deploying the recommended gadget.

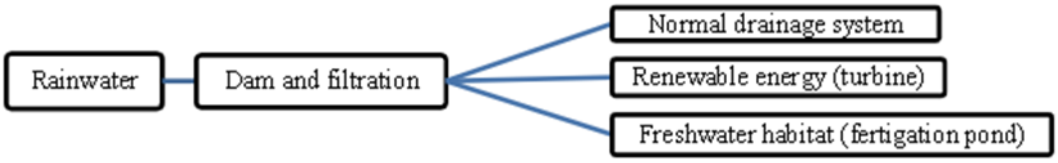

Fig. 3. Conceptual design of rainwater harvesting system at SMKIS [19]

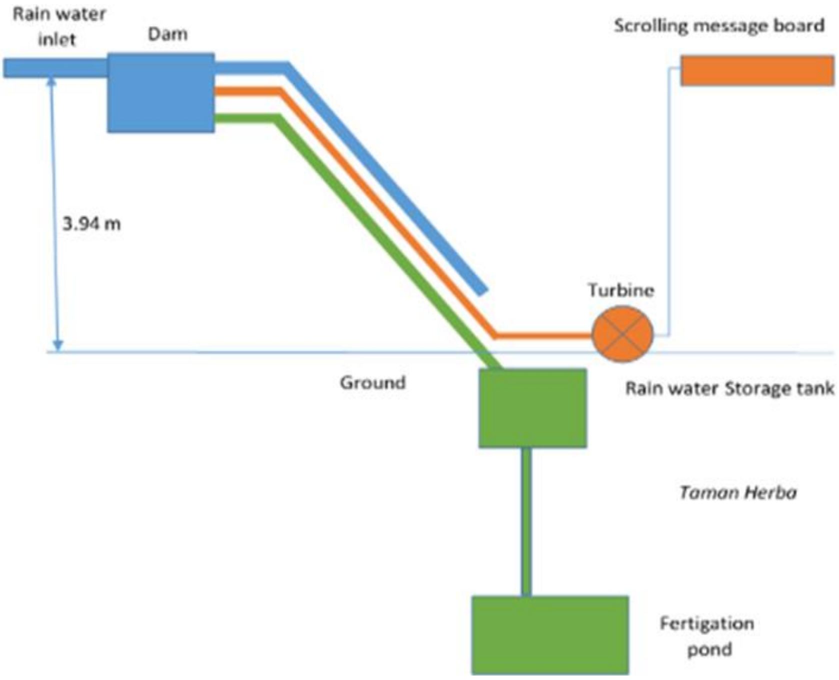

Fig. 4. Schematic diagram of the RWH system at SMKIS [19]

There are another concept of rainwater harvesting system varieties, roof harvesting system (RHS) and pond harvesting system (PHS) [22]. RHS, while frequently used, is constrained by its modest size. PHS shows increased promise, particularly in newly established humid tropical urban regions. The most major potential benefits of rainwater collection systems are based on rainfall depth. For comparable roof area and water consumption rates, higher rainfall depth is more reliable. Figure 5 and Figure 6 show two types of RHS storage tanks: above ground and underground. Additionally, Figure 7 illustrates the pond harvesting system.

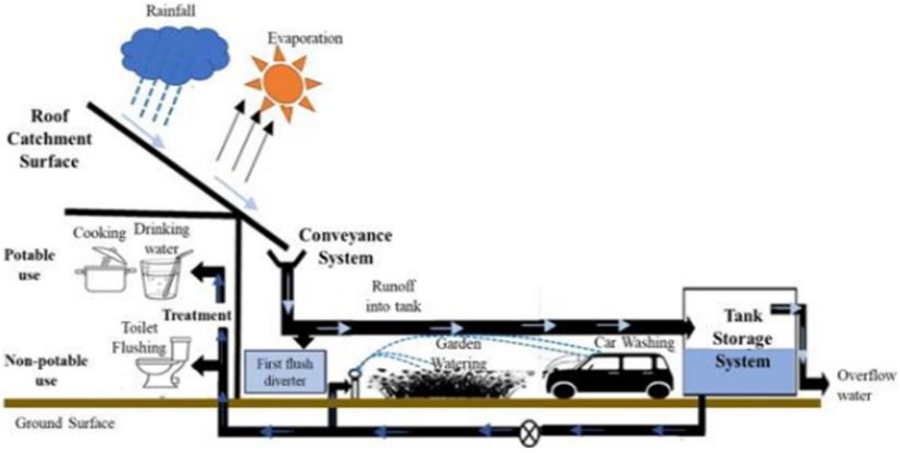

Fig. 5. RHS aboveground storage tanks [22]

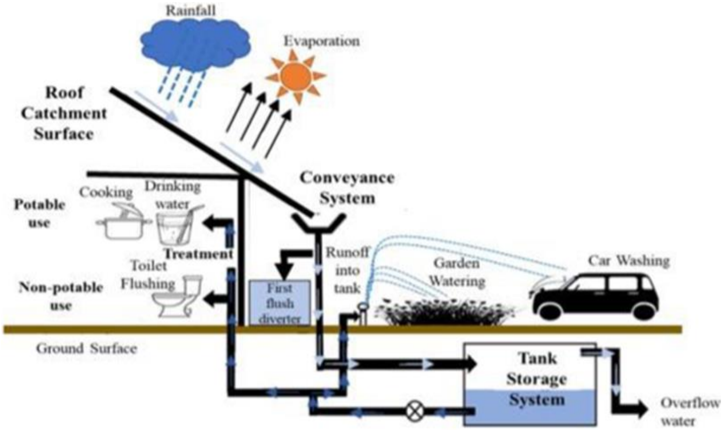

Fig. 6. RHS underground storage tanks [22]

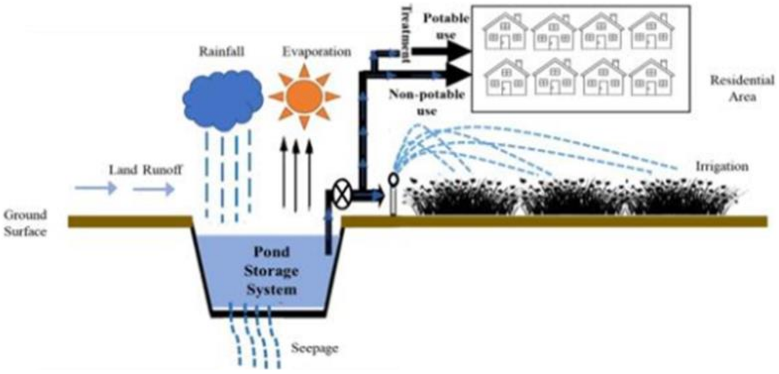

Fig. 7. Pond harvesting system [22]

2.3 Hybrid Solar PV and Micro-Hydro Technologies

Renewable energy sources have gained global prominence, yet their intermittent nature necessitates energy storage solutions. While hydroelectric reservoirs provide reliable energy storage, they require specific land topology and large-scale flooding. In contrast, solar PV systems offer simplicity and longevity but face power fluctuations due to weather conditions. The solution lies in a parallel and complementary hybrid microgeneration system that combines solar PV and micro-hydro. Solar panels capture sunlight during the day, converting it into electricity. This energy directly supplies daytime demand, powering homes, businesses, and communities [23]. While stored water energy from a small reservoir meets nighttime demand. Micro-hydro turbines generate electricity, utilizing the gravitational potential energy of flowing water. The system ensures continuous power supply, even during climatic variations [24]. The grid usually serves as a backup, stepping in when solar and micro-hydro resources are insufficient.

This hybrid approach optimizes power generation, minimizes fluctuations, and enhances reliability [25]. It demonstrates the feasibility of this proposal, even in scenarios without energy exchange with the grid. The proposed topology can also function as an off-grid system, benefiting remote areas and less developed regions [26. Two notable studies contribute to the understanding of hybrid systems. First, De Paris *et al.,* [23] proposed a novel hybrid microgeneration system composed of solar PV and hydropower, emphasizing the appropriate sharing of power between sources. Second, Shadman *et al.,* [27] explored the role of current and future renewable energy policies in fortifying Malaysia’s energy security through stakeholder engagement. These articles provide valuable insights into the design, optimization, and policy considerations for hybrid solar PV and micro-hydro technologies.

In conclusion, hybrid solar PV and micro-hydro technologies offer a promising solution for sustainable energy generation, particularly in regions with fluctuating solar resources and available water bodies. By combining the strengths of both technologies, these hybrid systems can enhance energy reliability, reduce environmental impact, and contribute to a sustainable energy future [28].

3. Methodology

3.1 System Operation

For this project, the main part of carrying out this procedure is quantifying the water that enters the rainwater storage tank from the rain gutter. The evaluation comprises measuring the amount of rainwater available for irrigation and tank flushing, as well as assessing the power generated by the hybridized solar and micro-hydro turbine sources, which are aided by the charge controller. Solar energy also acts as an alternate energy source when there is no rain. The stored voltage is then distributed between the battery and the Arduino UNO. Figure 8 shows the project's block diagram.

Solar energy is combined with a micro-hydro turbine that runs on direct current (DC) by connecting the two sources in parallel and using a Schottky diode to prevent current backflow between them. The voltage and current created by both sources are then routed to the charge controller, which regulates the current and voltage entering the battery, which functions as an energy storage unit. Simultaneously, the water flowing into the micro-hydro turbine is directed to the water flow sensor, which provides data on the water entering the rainwater storage tank. The Arduino Uno is powered by a boost converter, which regulates the battery voltage. The Arduino microcontroller reads information from the water flow sensor and displays it on the LCD screen. In addition, a DC water pump moves water for irrigation and into the flush tank for toilet use.

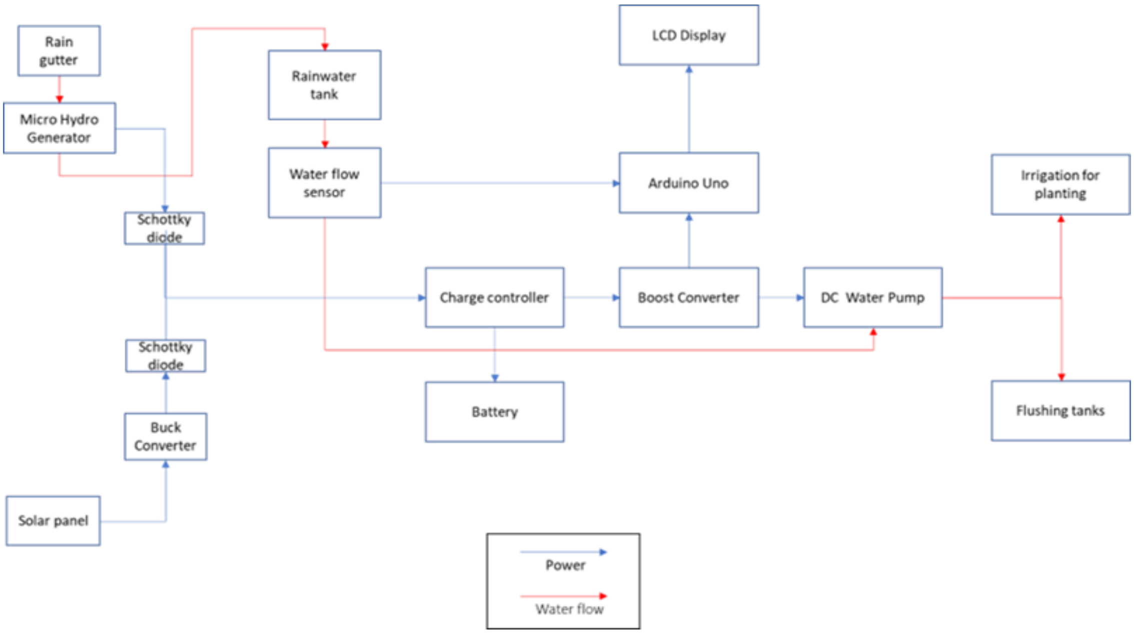

Fig. 8. Project Block Diagram

3.2 Project Design and Installation

Figure 9 depicts the project's final configuration, which consists of designated areas for solar panel, electronic component storage, and a dedicated space to accommodate the rainwater reservoir, pipeline, water turbine, and pump.

Fig. 9. Final shape of the project

The original planning considered the material type and dimensions to ensure an easy design of the project shape. To build a strong and sturdy structure, approximate measures were derived using the height and dimensions of the rainwater storage reservoir. The emphasis was on durability, heat, and corrosion resistance, which led to the selection of iron slotted angle bars.

3.3 Experiment Setup for Case A, Case B and Case C

The first set of experiments, marked as case A, is intended to investigate solar energy's power-generating potential. For Case A the electricity is supplemented by a solar charge controller, which charges the battery and regulates the load on the project system. The system consists of a relay-controlled motor (DC water pump) and a liquid crystal display (LCD) that shows the water volume in the tank. Case B, the second series of trials, is nearly identical to case A, with the exception that the micro-hydro turbine is substituted by a solar function as the energy source. Case C, the third and final series of experiments, seeks to evaluate the performance of hybrids made up of diodes connected in series at positive wires between two energy sources: micro-hydro turbines and solar panels. Table 1 shows the source type and mode for each associated case.

Table 1
Description of each experiment conduct

Cases	Source Type	Mode
Case A	Use only solar	12 hours - 55 minutes water pump off and 5 minutes water pump on
Case B	Use only micro-hydro turbine	12 hours - water pump off
Case C	Use hybrid of solar and micro-hydro turbine	12 hours - 55 minutes water pump off and 5 minutes water pump on

4. Results

4.1 Data Collection

The experiments were designed to successfully collect and analyse data, with an emphasis on voltage and current readings from solar panels and micro-hydro turbines show in Figure 10, Figure 11, and Figure 12 for case A, B, and C. Real-time measurements were taken with electrical equipment such as clamp metres and multimeter. To measure water flow, a bespoke water flow sensor was built utilising an Arduino Uno microcontroller.

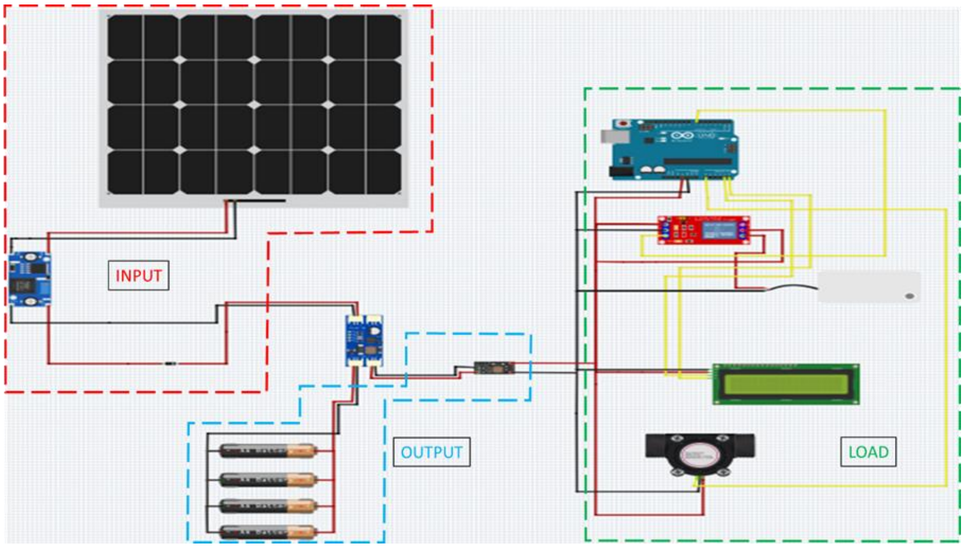

Fig. 10. Point of data measured in Case A

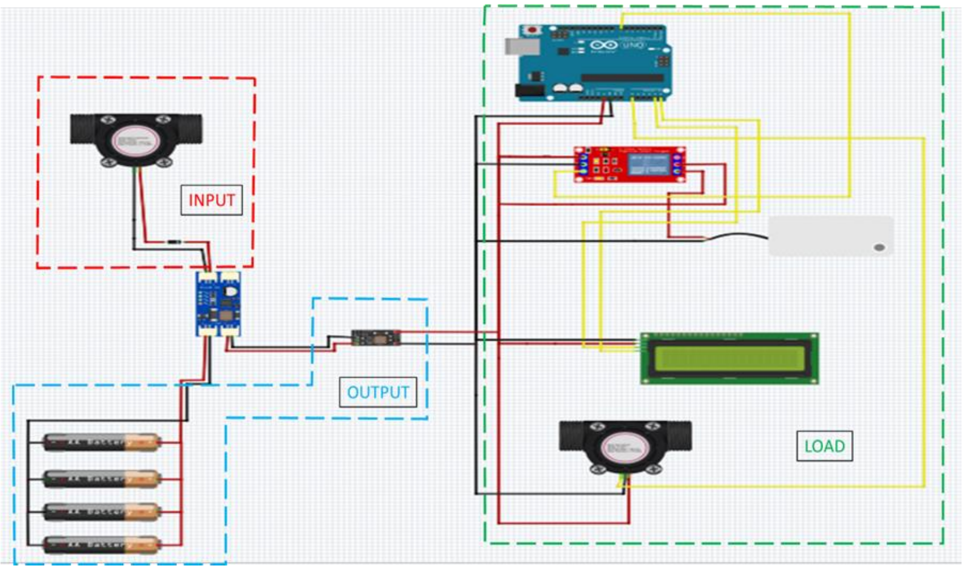

Fig. 11. Point of data measured in Case B

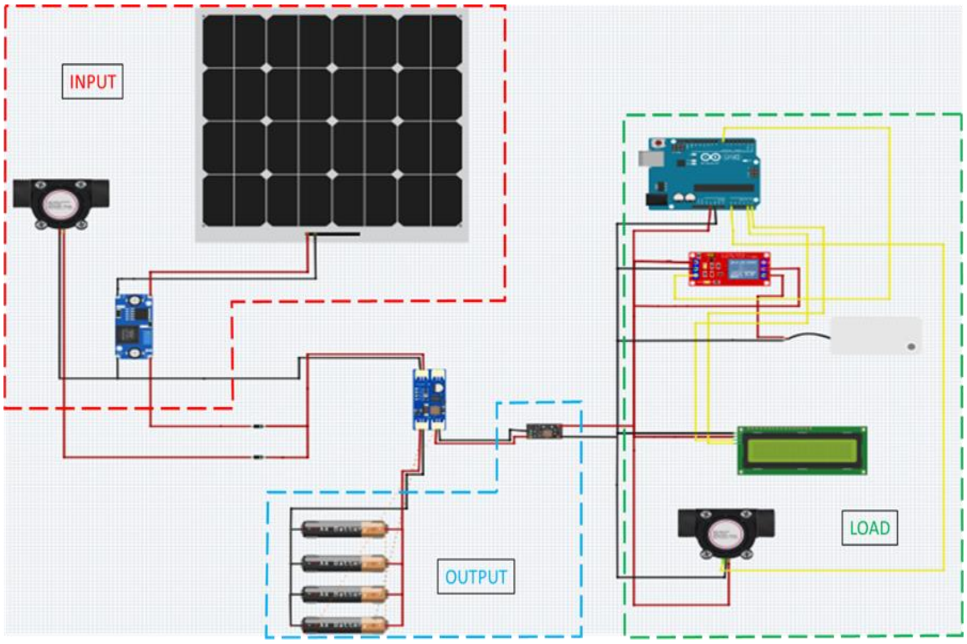

Fig. 12. Point of data measured in Case C

4.1.1 Case A

The data is categorized into input and output components to enhance organization and comprehension of the analysis. Information is collected at 55-minute intervals when the water pump is off and at 5-minute intervals when it is operational. The time specified in the Arduino Uno code, governing the relay, dictates the conditions.

(i) Input for Case A

The data that was successfully gathered for the Case A experiment for input analysis, which was carried out at 25/11/2023 from 9.20 a.m to 7.25 p.m, is represented in Table 2.

Figure 13 and Figure 14 show the voltage, current, and power curves for a solar-powered system. The initial graph depicts the time-dependent voltage and current of the solar panel. The voltage remains rather consistent at roughly 20 volts for most of the day, with a typical drop to 3.26 volts in the evening. In contrast, the current is very variable, with distinct peaks and troughs, indicating that altering sunlight intensity or cloud cover could have an impact. The second graph depicts solar power in watts, calculated from the product of voltage and current. Power levels peak at about 4.5 watts at about 2:20 p.m., mirroring current fluctuations.

Table 2
Input data for Case A experiment

Time	Solar voltage, V	Solar current, A	Power, W
9.20am	19.2	0.13	2.50
9.25am	19.6	0.07	1.37
10.20am	20.6	0.13	2.68
10.25am	20.8	0.08	1.66
11.20am	21.7	0.13	2.82
11.25am	21.2	0.1	2.12
12.20pm	21.5	0.15	3.23
12.25pm	21.4	0.1	2.14
1.20pm	20.3	0.14	2.84
1.25pm	20.8	0.08	1.66
2.20pm	21.3	0.22	4.69
2.25pm	20.7	0.11	2.28
3.20pm	20.1	0.13	2.61
3.25pm	20.6	0.01	0.21
4.20pm	19.5	0.16	3.12
4.25pm	21.7	0.03	0.65
5.20pm	19.5	0.14	2.73
5.25pm	20.2	0.05	1.01
6.20pm	8.9	0.04	0.36
6.25pm	9.15	0.06	0.55
7.20pm	3.76	0.03	0.11
7.25pm	3.26	0.02	0.07

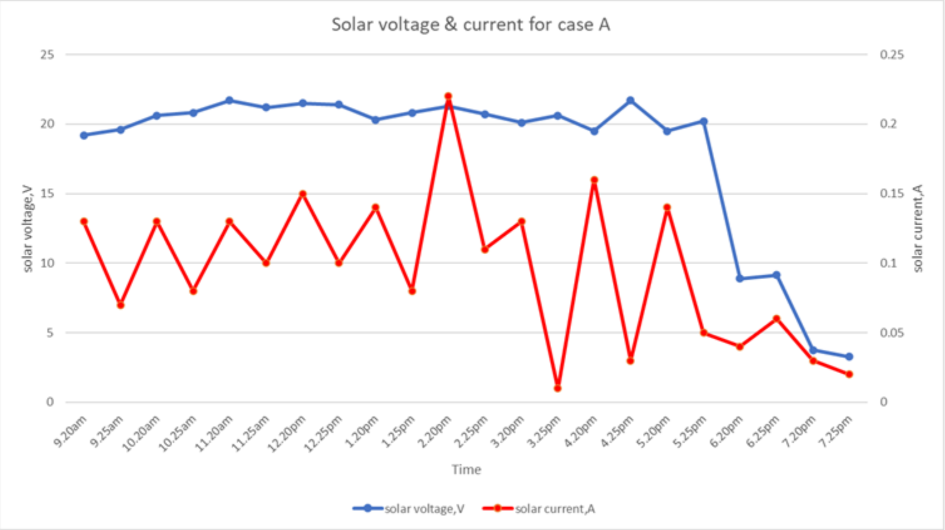

Fig. 13. Input voltage and current graph for Case A

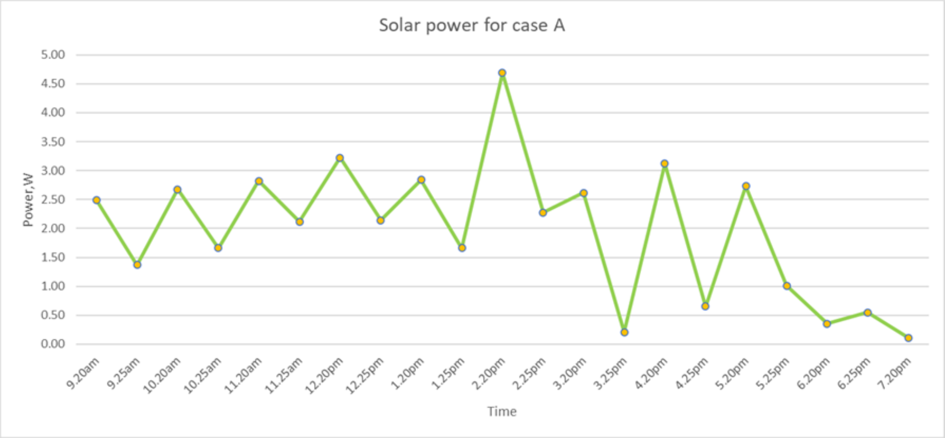

Fig. 14. Input power graph for Case A

(ii) Output for Case A

Case A has had satisfactory data collection results. Table 3 and Table 4 show the findings of an output analysis experiment conducted from 9:20 a.m. to 7:25 p.m.

Table 3
Output data (battery) for Case A experiment

Time	Battery voltage, V	Battery current, A	Power, W	Mode Charge, C or Discharge, D
9.20am	4.1	-0.32	-1.31	Discharge
9.25am	4.1	0.09	0.37	Charge
10.20am	4.1	0.12	0.49	Charge
10.25am	4.1	0.08	0.33	Charge
11.20am	4.2	0.12	0.50	Charge
11.25am	4.1	0.06	0.25	Charge
12.20pm	4.2	0.11	0.46	Charge
12.25pm	4.2	0.04	0.17	Charge
1.20pm	4.1	0.12	0.49	Charge
1.25pm	4	-0.06	-0.24	Discharge
2.20pm	4.1	0.22	0.90	Charge
2.25pm	4	-0.03	-0.12	Discharge
3.20pm	4.1	0.1	0.41	Charge
3.25pm	4	-0.13	-0.52	Discharge
4.20pm	4.2	0.11	0.46	Charge
4.25pm	4.1	-0.09	-0.37	Discharge
5.20pm	4.1	0.14	0.57	Charge
5.25pm	4	-0.08	-0.32	Discharge
6.20pm	3.8	-0.26	-0.99	Discharge
6.25pm	3.95	-0.08	-0.32	Discharge
7.20pm	3.76	-0.34	-1.28	Discharge
7.25pm	3.85	-0.16	-0.62	Discharge

Table 4
Output data (overall load) for Case A experiment

Time	Load ON voltage, V	Load ON current, A	Power in, W	Load 0FF voltage, V	Load OFF current, A	Power out, W
9.20am	4.1	0.27	1.11	5	0.12	0.60
9.25am	4.1	0.11	0.45	5	0.08	0.40
10.20am	4	0.28	1.12	5	0.08	0.40
10.25am	4	0.14	0.56	5	0.11	0.55
11.20am	4.1	0.28	1.15	5	0.22	1.10
11.25am	4	0.14	0.56	5	0.1	0.50
12.20pm	4.1	0.28	1.15	5	0.21	1.05
12.25pm	4.1	0.13	0.53	5	0.1	0.50
1.20pm	4	0.28	1.12	5	0.21	1.05
1.25pm	3.9	0.14	0.55	5	0.11	0.55
2.20pm	4	0.34	1.36	5	0.25	1.25
2.25pm	3.9	0.17	0.66	5	0.13	0.65
3.20pm	3.9	0.23	0.90	5	0.15	0.75
3.25pm	3.9	0.09	0.35	5	0.02	0.10
4.20pm	4.1	0.25	1.03	5	0.15	0.75
4.25pm	4	0.08	0.32	5	0.05	0.25
5.20pm	4	0.25	1.00	5	0.17	0.85
5.25pm	4	0.11	0.44	5	0.06	0.30
6.20pm	3.5	0.29	1.02	5	0.17	0.85
6.25pm	3.86	0.11	0.42	5	0.06	0.30
7.20pm	3.55	0.22	0.78	5	0.1	0.50
7.25pm	3.78	0.04	0.15	5	0.02	0.10

Figure 15, Figure 16, Figure 17, and Figure 18 show the power trends as well as the periodic voltage and current evolution of a system powered by a battery and an overall load. It is usual practice in lithium-ion battery discharge and charge cycles to keep the voltage over 4.0 V throughout the day. Consistent readings that exceed the nominal 3.7 V indicate a healthy, positively charged battery. Negative current implies discharge, whereas positive current suggests charging. Negative current levels indicate battery power consumption, which could be due to load or system inefficiencies. Variable loads or intermittent charging caused by passing clouds might result in current fluctuations. During charging, power output rarely exceeds 0.5 watt. With a battery capacity of 62.16 Wh, the somewhat sluggish charging rate indicates that relying entirely on solar energy may not be sufficient to fully charge the battery within a reasonable timeframe. The whole load maintains a constant voltage, with minor oscillations around 5.0 volts. Stability is critical in applications that require constant voltage levels. Sharp current surges could indicate changing power consumption or intermittent power on/off cycles in the load. The frequency of these spikes shows that there is a control mechanism or a periodic load. The system's capacity to maintain steady voltages during operation is encouraging, especially given the water pump's autonomous operation and enough battery recharge, which ensure proper system functionality.

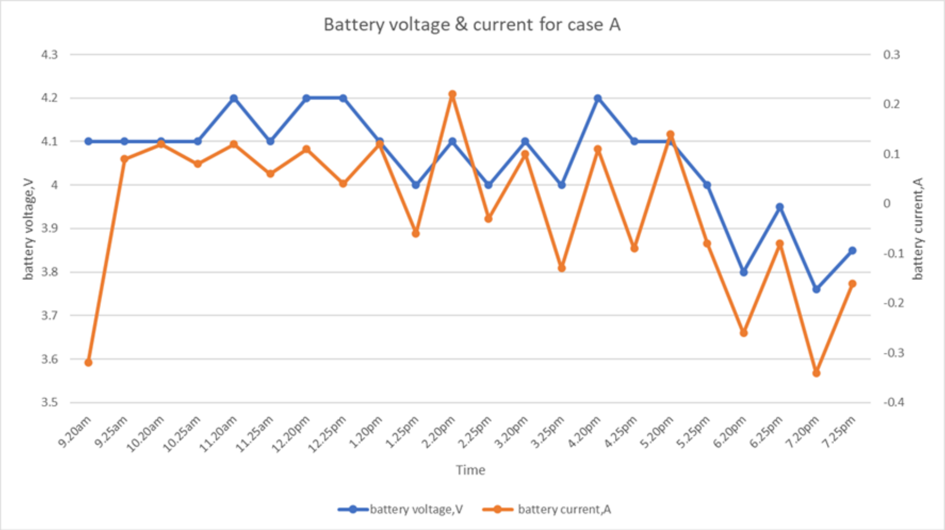

Fig. 15. Output (battery) voltage and current graph for Case A

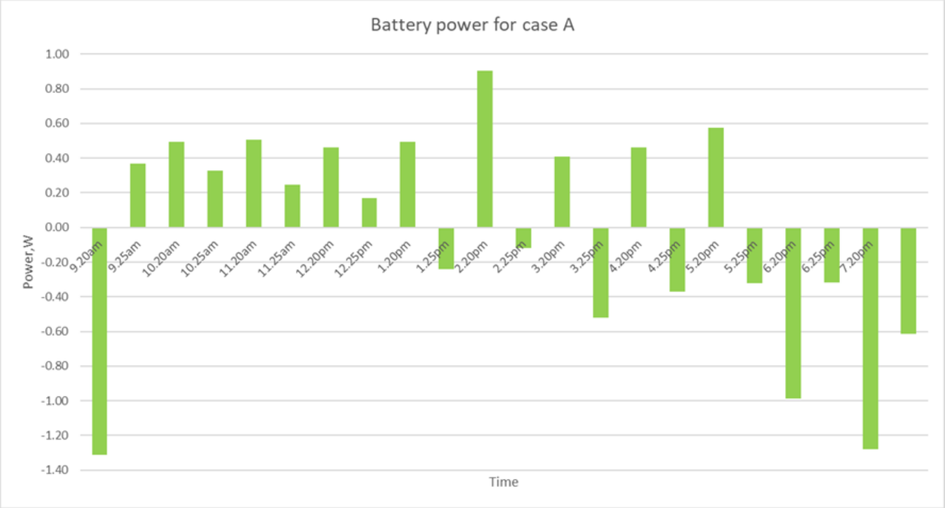

Fig. 16. Output (battery) power graph for Case A

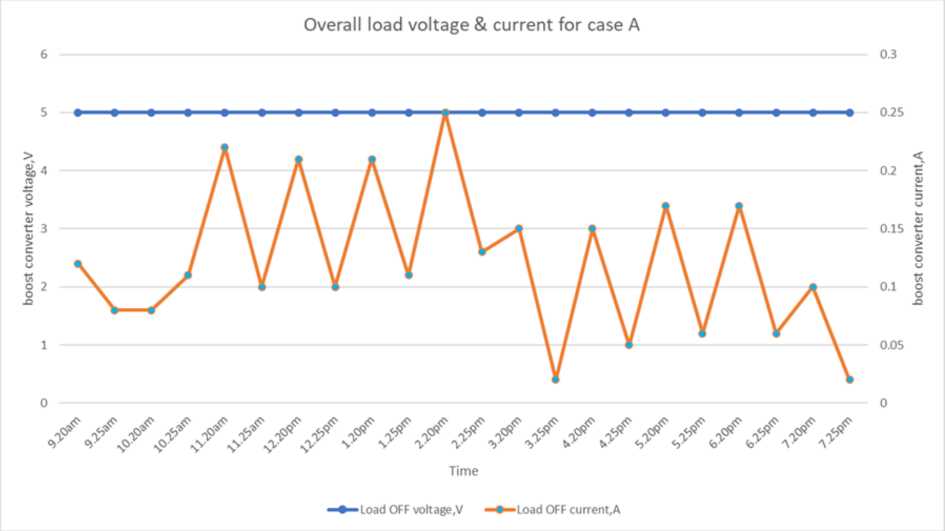

Fig. 17. Output (overall load) voltage and current graph for Case A

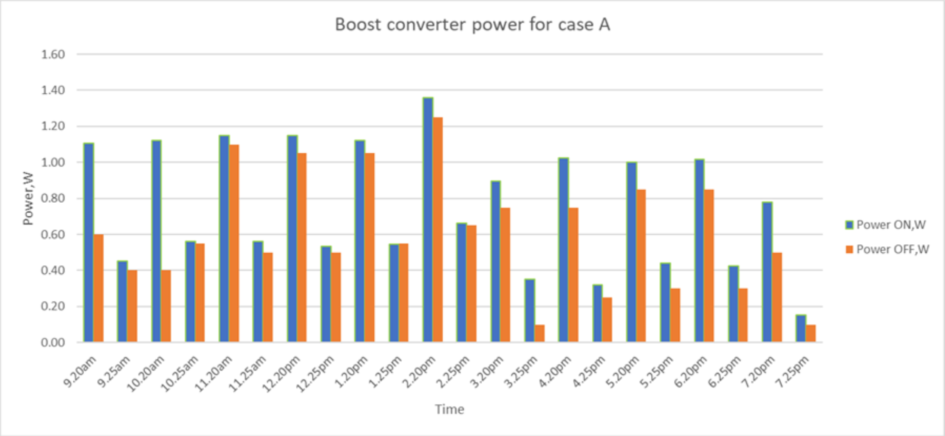

Fig. 18. Output (overall load) power graph for case A

4.1.2 Case B

The data is divided into two components: input and output. Measurements are conducted every 30 minutes to assess the micro hydro turbine's ability to generate voltage and current for charging the system's battery. The system is configured to deactivate the relay for 12 hours, which corresponds to the water pump's rest mode. The micro hydro turbine is fed tap water to simulate how it would operate while collecting rainwater from a gutter system. This guarantees that the water flow is uniform, and the current is stable.

(i) Input for Case B

The input data that was gathered in a successful manner for the case B experiment, which lasted from 4:20 pm to 7:50 pm at 9/12/2023, is presented in Table 5.

Table 5
Input data (micro-hydro turbine) for Case B experiment

Time	Turbine voltage, V	Turbine current, A	Power, W
4.20pm	11.2	0.04	0.448
4.50pm	11.2	0.03	0.336
5.20pm	11.2	0.04	0.448
5.50pm	11.1	0.03	0.333
6.20pm	11.3	0.02	0.226
6.50pm	11.3	0.04	0.452
7.20pm	11.3	0.03	0.339
7.50pm	11.2	0.02	0.224

Figure 19 and Figure 20 show the periodic evolution of voltage and current flow in a system powered by energy from a micro hydro turbine, demonstrating the system's operating dynamics. While the voltage remains rather stable, fluctuating very slightly around 11.2 volts, the current varies significantly, peaking at roughly 0.04 amperes. Notably, the voltage is consistently stable. The micro hydro turbine output is stable, with predicted fluctuations probable due to changes in water flow or load demands. Overall, the statistics show that the micro hydro turbine functions well and contributes effectively to the charging system. These deviations are within an acceptable range for a system designed to charge an 18650 lithium-ion battery, using the power of a solar charge controller supplied by a 12-volt, 2.65-watt micro hydro turbine.

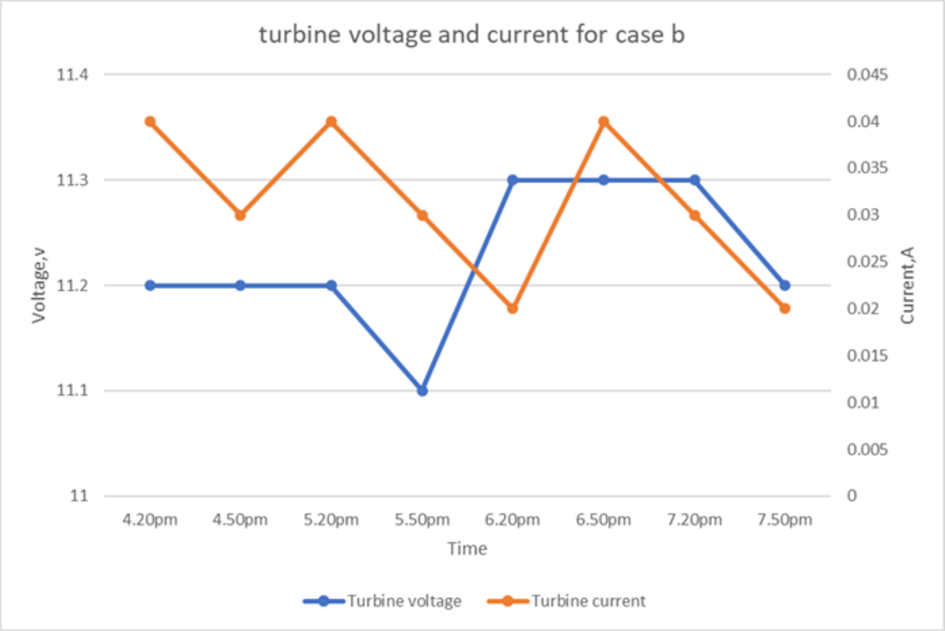

Fig. 19. Input voltage and current graph for Case B

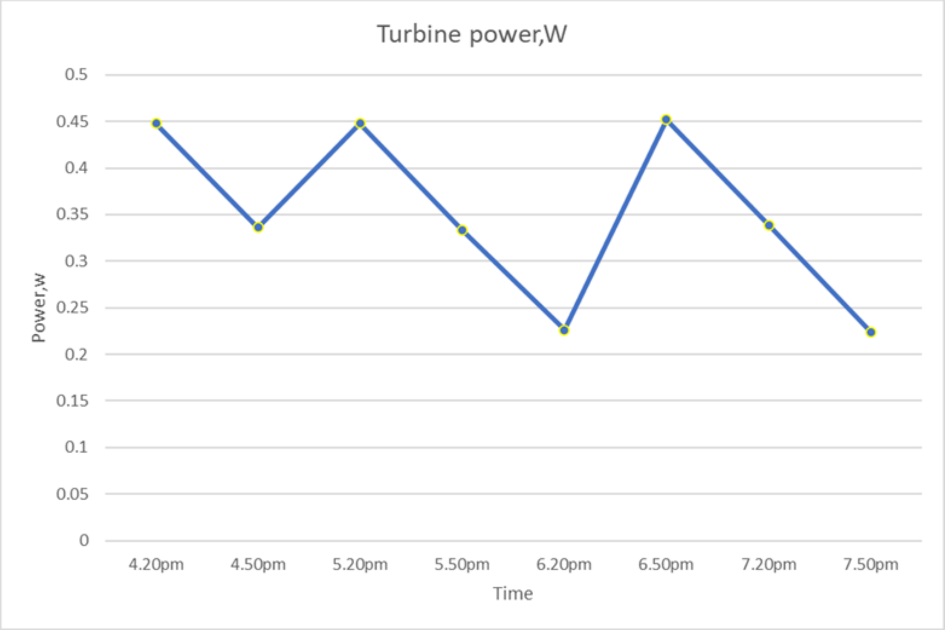

Fig. 20. Input power graph for Case B

(ii) Output for Case B

The output data has been gathered satisfactorily for the Case B. The data depicted in Table 6 and Table 7 illustrates an output analysis experiment that spanned the time from 4:20 in morning time to 7:50 in the evening.

Table 6
Output data (battery) for Case B experiment

Time	Battery voltage, V	Battery current, A	Power, W	Mode charge and discharge
4.20pm	3.2	0.02	0.064	Charge
4.50pm	3.3	0.02	0.066	Charge
5.20pm	3.3	0.02	0.066	Charge
5.50pm	3.3	0.01	0.033	Charge
6.20pm	3.3	0.01	0.033	Charge
6.50pm	3.3	0.01	0.033	Charge
7.20pm	3.3	0.02	0.066	Charge
7.50pm	3.4	0.01	0.034	Charge

Table 7
Output data (overall load) for Case B experiment

Time	Load ON voltage, V	Load ON current, A	Power ON, W	Load OFF voltage, V	Load OFF current, V	Power OFF, W
4.20pm	3.2	0.07	0.224	4.8	0.03	0.144
4.50pm	3.3	0.05	0.165	5	0.02	0.1
5.20pm	3.2	0.05	0.16	4.8	0.03	0.144
5.50pm	3.2	0.06	0.192	4.8	0.04	0.192
6.20pm	3.2	0.05	0.16	4.8	0.03	0.144
6.50pm	3.2	0.05	0.16	4.8	0.02	0.096
7.20pm	3.2	0.06	0.192	4.8	0.03	0.144
7.50pm	3.3	0.05	0.165	4.9	0.02	0.098

Figure 21 to Figure 24 show power trends as well as periodic voltage and current progression in a system that includes a boost converter and a battery. Within two and a half hours, the battery voltage climbs from 3.2 to 3.4 volts, demonstrating that the micro hydro turbine is effectively recharging the battery. This voltage increases during the recharging process, which begins at the water pump's minimum working level of 3.2 volts, signifies a successful recharging cycle. The turbine voltage is maintained via a piped water supply. Fully depleted lithium-ion batteries typically register 3.0 volts, with a full charge of 4.2 volts. Consistent performance around the lower threshold may indicate approaching discharge limits or partial charging changes in potable water flow cause voltage and current changes. The boost converter maintains a relatively constant voltage of 4.8 to 5 volts, ensuring steady power delivery to the load. Current, which varies between 0.045 and 0.07 amperes, may be influenced by load fluctuations or changes in boost converter efficiency. The system's independent water pump operation, which is not dependent on external power, guarantees effective maintenance through battery recharging.

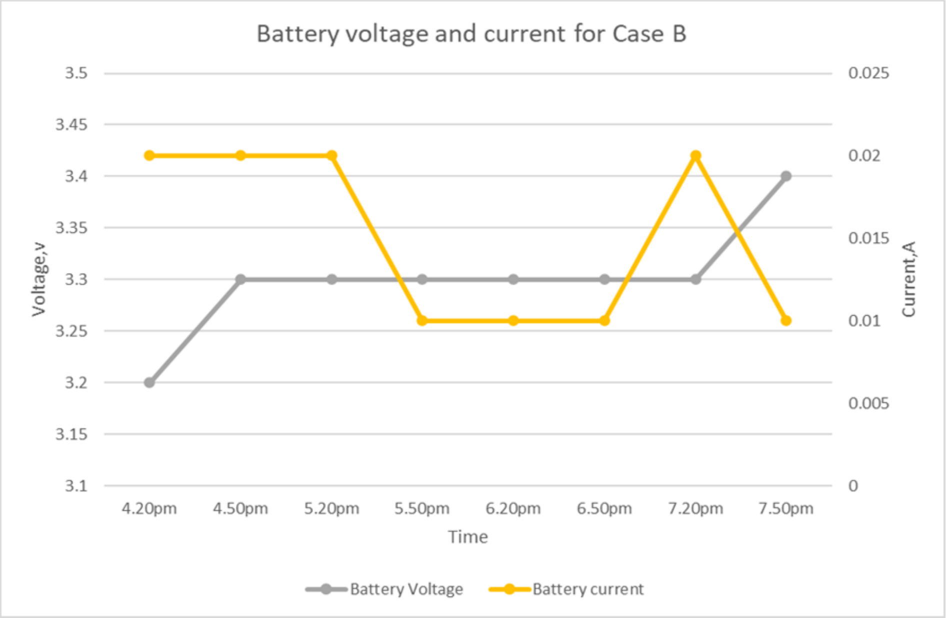

Fig. 21. Output (battery) voltage and current graph for Case B

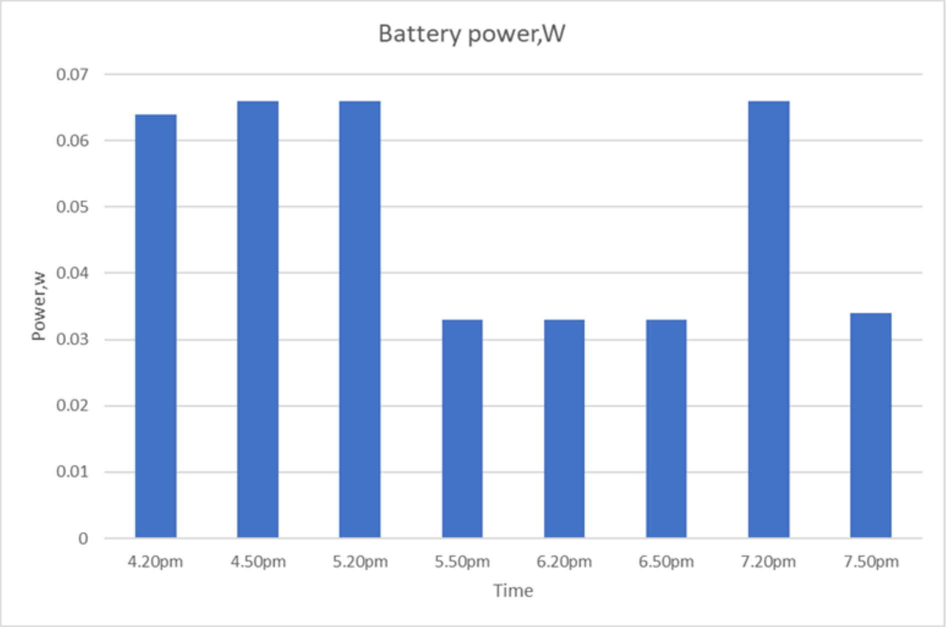

Fig. 22. Output (battery) power graph for Case B

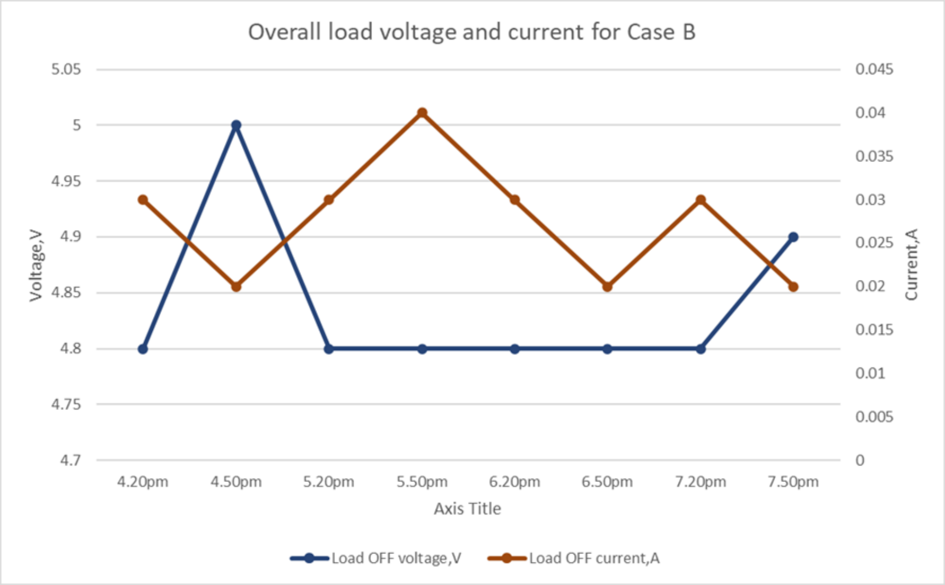

Fig. 23. Output (overall load) voltage and current graph for Case B

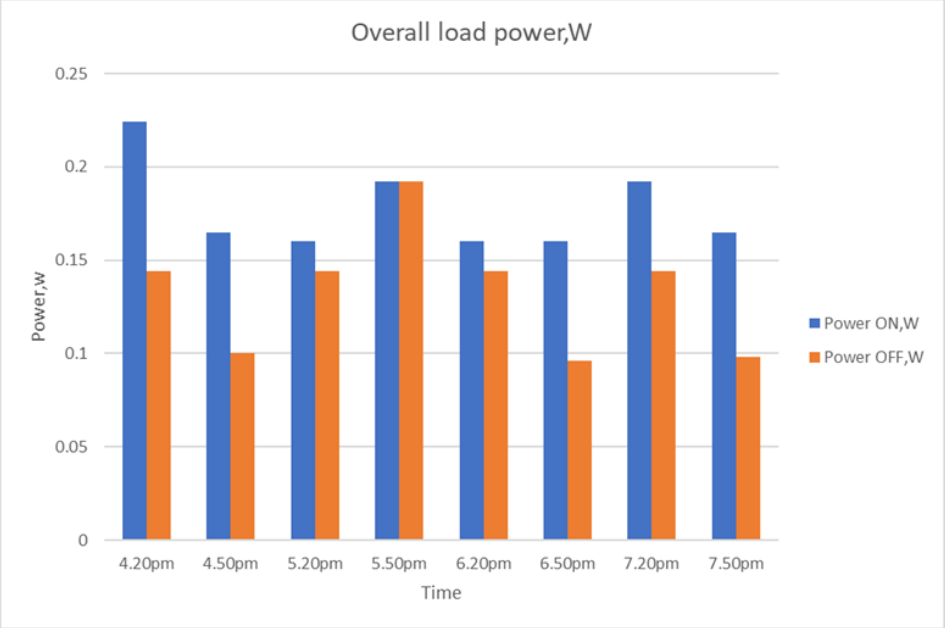

Fig. 24. Output (overall load) power graph for Case B

4.1.3 Case C

The data is separated into two categories: input and output. Data is collected at 10-minute intervals to analyse the voltage and current capabilities of the system's solar panels and micro-hydro turbine, which are used for battery charging. A diode is installed in the positive wires of both the solar panel and the micro hydro turbine to prevent unwanted current flow between the two sources. Running water is fed into the partially opened micro hydro turbine to maintain a constant water flow and current. Simultaneously, the solar panel is continually exposed to light, allowing for continuous energy conversion.

(i) Input for Case C

The input data obtained for the Case C experiment, which was conducted between 11.35 am and 2.35 pm at 23/12/2023, is displayed in Table 8.

Table 8
Input data (solar + micro-hydro turbine) for Case C experiment

Time	Solar+turbine voltage, V	Solar+turbine current, A	Power, W
11.35pm	12.6	0.16	2.016
11.45pm	12.6	0.12	1.512
12.05pm	12.6	0.1	1.26
12.30pm	12.2	0.14	1.708
12.35pm	12.2	0.08	0.976
1.05pm	12.2	0.08	0.976
1.30pm	12.3	0.13	1.599
1.35pm	12.2	0.01	0.122
2.05pm	11.2	0.1	1.12
2.30pm	12.3	0.13	1.599
2.35pm	12.2	0.02	0.244

Figure 25 exhibits linear variations in current and voltage, whereas Figure 26 depicts power flow in a hybrid energy system that includes a solar panel and a micro hydro turbine (case C). The voltage range of 12.2 and 12.6 volts indicates the hybrid system's capacity to sustain a consistent voltage. In contrast, the current fluctuates significantly, with sudden surges and dips that could be attributed to different outputs from the solar and micro hydro turbine sources, as well as changes in the demand of the linked load. The power graph follows a similar pattern, suggesting a direct relationship between power and current in an electrical system (measured as the product of current and voltage). The minimum power is around one watt, while the highest power is approximately two watts. Discrepancies in power output indicate intermittent stability in energy production from micro hydro and solar sources, which could be influenced by environmental factors such as cloud cover affecting solar output or water flow changes affecting the micro turbine.

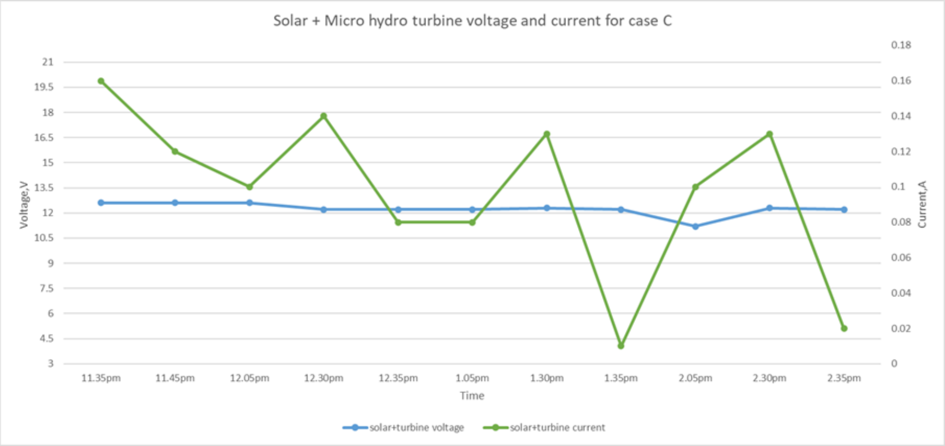

Fig. 25. Input voltage and current graph for Case C

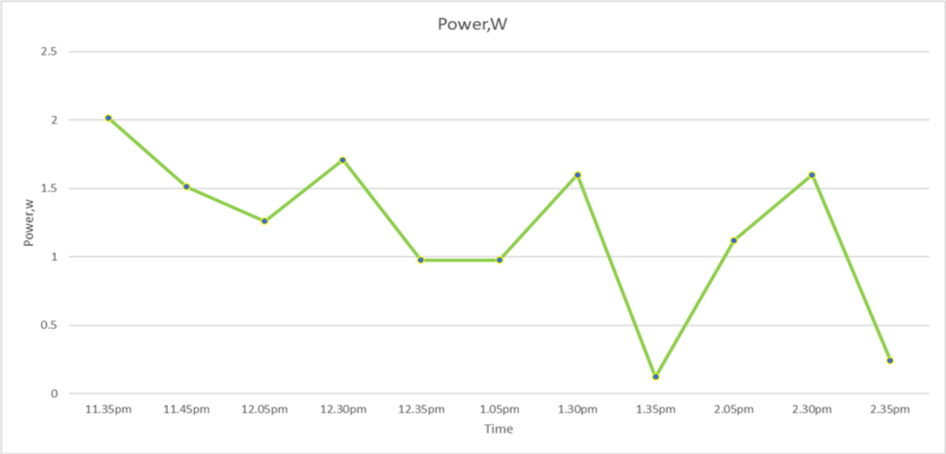

Fig. 26. Input power graph for Case C

(ii) Output for Case C

The output data has been gathered satisfactorily for the Case C. The data depicted in Table 9 and Table 10 illustrate an output analysis experiment that spanned the time from 11.35 in morning time to 2.35 pm in the evening.

Table 9
Output data (battery) for Case C experiment

Time	Battery voltage, V	Battery current, A	Power, W	Mode charge and discharge
11.35pm	4.1	0.24	0.984	Charge
11.45pm	4.1	0.17	0.697	Charge
12.05pm	4.1	0.14	0.574	Charge
12.30pm	4.1	0.09	0.369	Charge
12.35pm	4.1	0.08	0.328	Charge
1.05pm	4.1	0.08	0.328	Charge
1.30pm	4.1	0.09	0.369	Charge
1.35pm	4	-0.09	-0.36	Discharge
2.05pm	4.1	0.06	0.246	Charge
2.30pm	4.1	0.1	0.41	Charge
2.35pm	4	-0.08	-0.32	Discharge

Table 10
Output data (overall load) for Case C experiment

Time	Load ON voltage, V	Load ON current, A	Power ON, W	Load OFF voltage, V	Load OFF current, A	Power OFF, W
11.35pm	4.1	0.11	0.451	5	0.07	0.35
11.45pm	4.1	0.08	0.328	5	0.05	0.25
12.05pm	4.1	0.1	0.41	5	0.05	0.25
12.30pm	4	0.23	0.92	5	0.15	0.75
12.35pm	4.1	0.1	0.41	5	0.06	0.3
1.05pm	4.1	0.1	0.41	5	0.06	0.3
1.30pm	4	0.24	0.96	5	0.16	0.8
1.35pm	3.9	0.09	0.351	5	0.07	0.35
2.05pm	4	0.11	0.44	5	0.07	0.35
2.30pm	4	0.23	0.92	5	0.15	0.75
2.35pm	3.9	0.1	0.39	5	0.05	0.25

Figure 27 to Figure 30 demonstrate the power trends, periodic voltage, and current progression in a battery and boost converter-powered system that uses a hybrid micro hydro turbine and solar energy for voltage replenishment. The battery voltage begins at 4.1 volts and stabilizes within the predicted range for a fully charged lithium-ion battery, indicating its ideal functioning status. Negative current signifies discharge, whereas positive current shows battery charging, as shown in the current graph, which depicts a discharge phase followed by regeneration. As solar energy becomes less abundant, the micro hydro turbine takes on the major role of providing constant voltage. A continuous water flow maintains the turbine's voltage and current, with voltage oscillations linked to variations in water consumption flow. The boost converter provides a consistent output voltage of around 5 volts, which is critical for sensitive electrical devices, with slight variations. Changes in boost converter efficiency or load variations can cause significant current swings. The power graph, which is directly associated with current, shows discrete peaks of around 1 watt, which could be caused by increasing load demand or boost converter efficiency moments. The system's design prioritizes water pump control without relying on external power sources, ensuring maintenance through battery replenishment.

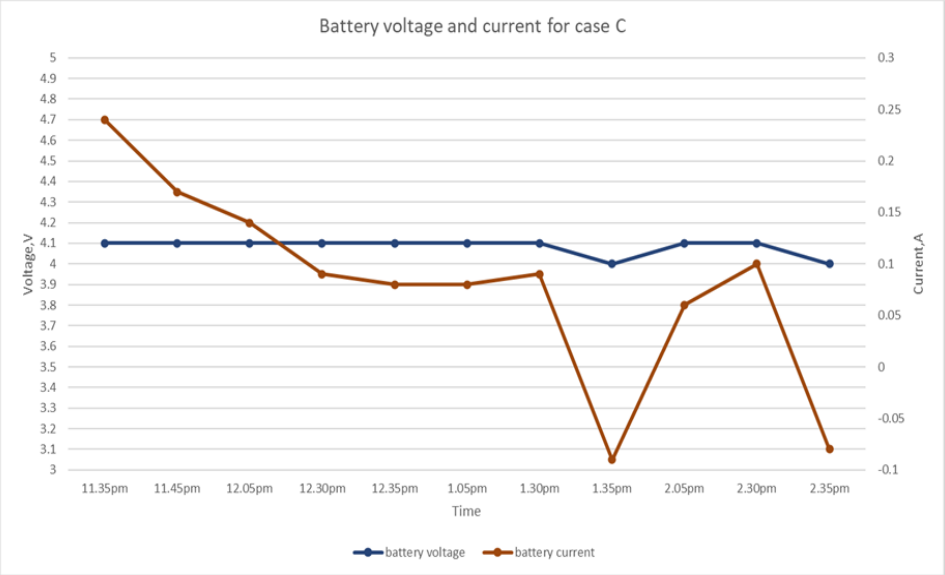

Fig. 27. Output (battery) voltage and current graph for Case C

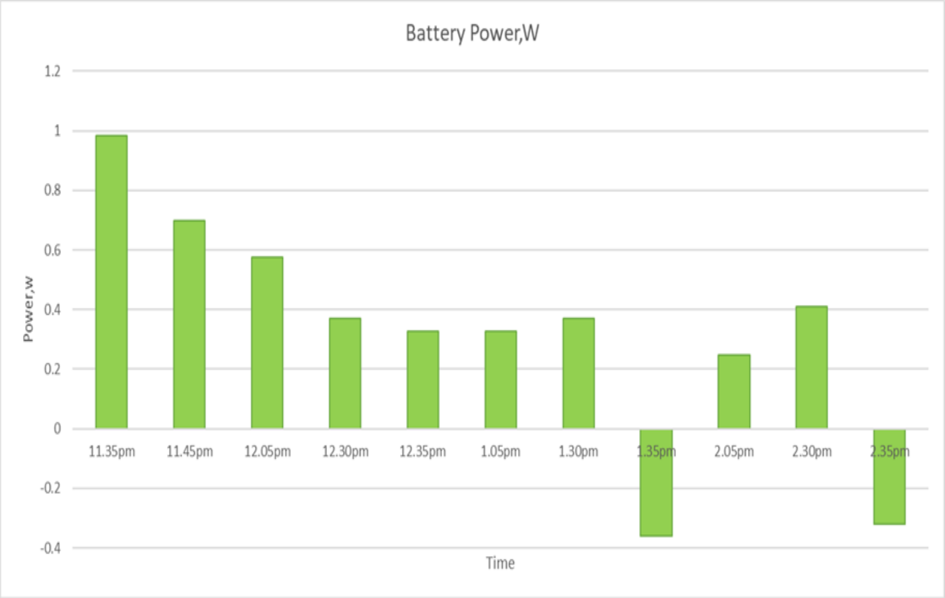

Fig. 28. Output (battery) power graph for Case C

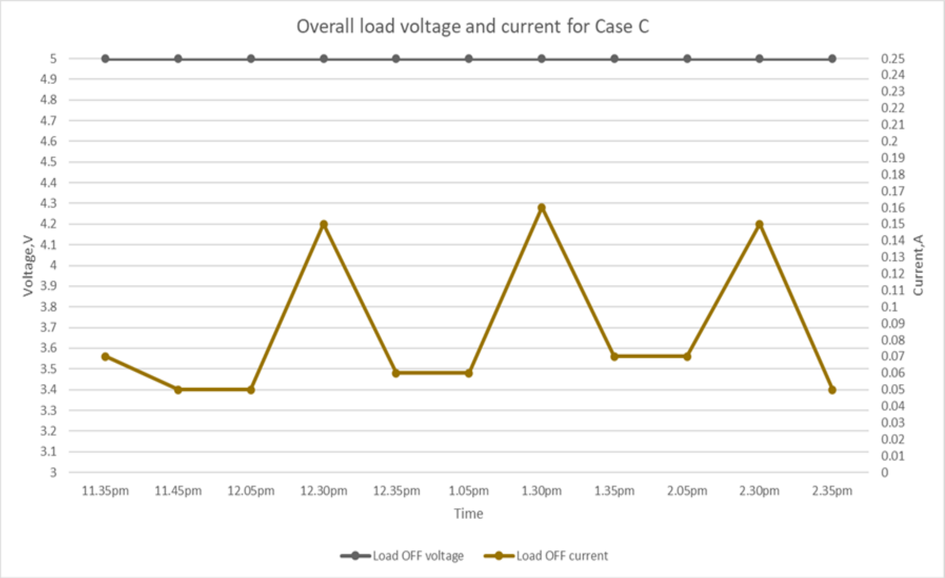

Fig. 29. Output (overall load) voltage and current graph for Case C

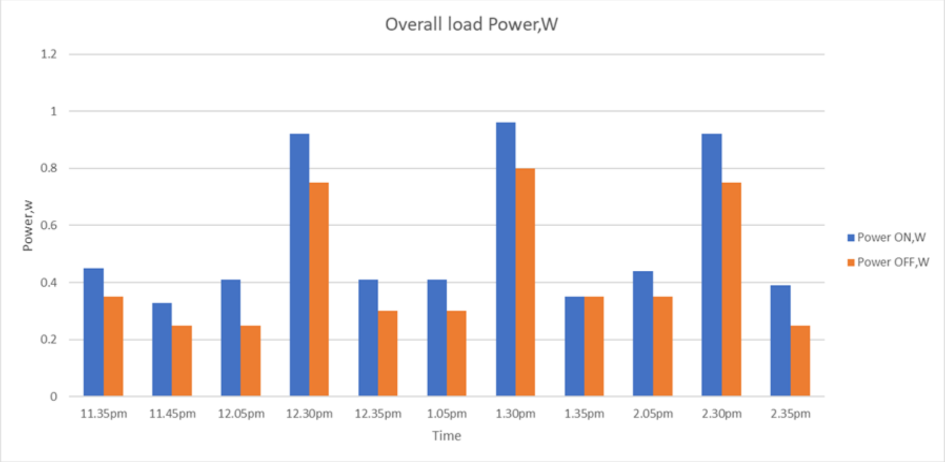

Fig. 30. Output (overall load) power graph for Case C

4.2 Comparison of Battery Charging and Discharging for Each Case

This section describes the battery charging and discharging procedures for the three cases studied: Case A, Case B, and Case C. Case A shows a balanced interplay of input and output energy, with a mean charging power of 0.462 kW and a mean discharging power of -0.18 kW. At a charge-to-discharge ratio of 75%, charging takes precedence, but significant discharging currents indicate possible energy dissipation during power output periods. The device's voltage stability above 3.8 V with minor variations suggests adequate energy retention capacity, while greater depletion rates over time may have an influence on battery health.

Case B shows a steady but modest charging process, with the voltage gradually increasing from 3.2 V to 3.4 V and an average charging power of 0.049 kW. Limited discharge means a constant but low-intensity energy source. High voltage stability, with a standard deviation of 0.053 V, indicates continuous and predictable charging, making it suited for applications that require a stable yet low-power supply.

Case C depicts an energy system in equilibrium, with a high 81.8% charge-to-discharge ratio that Favors charging activities. The mean charging power is consistently high at 0.478 kW, whereas the mean discharging power is relatively low at -0.34 kW, reducing energy loss during discharge. A low battery voltage standard deviation (0.040 V) and a consistent reading of around 4.1 V imply stable energy storage and good battery health. Overall, Case C provides a solid charging methodology with consistent voltage levels, which contributes to a longer battery life. Table 11 shows detailed values for each dataset.

Table 11
Data Comparison for each case

Data	Cases		
	Case A	Case B	Case C
Average Charging Power, kW	0.462	0.049	0.478
Average Discharging Power, kW	-0.18	0	-0.34
Charge to Discharge Percentage, %	75	0	81.8
Voltage Stability, V	0.078	0.053	0.039

Overall, Cases A and C are appropriate for this project. Case A exhibits the solar panel's capacity to charge effectively independently. Case C, on the other hand, not only provides somewhat more power but also maintains a higher charge-to-discharge ratio and greater voltage stability both of which are critical for efficient battery charging and lifetime. Case C's hybrid system performs better overall, resulting in more consistent and efficient charging and discharging. This suggests a more dependable system capable of handling fluctuating energy demands while providing a consistent energy supply to the battery. Such dependability is especially important for projects with fluctuating loads or that require regular energy delivery under varying conditions.

5. Conclusions

In summary, the literature study emphasises the value of water harvesting systems in mitigating water scarcity concerns, hence emphasising the necessity of such initiatives. The implementation of rainwater harvesting systems poses significant challenges, necessitating further research and competence in the subject.

The establishment of a methodology for the development of a hybrid micro-hydro and solar PV generation system inside a rainwater collection framework is an essential measure in effectively tackling various issues. The project presents essential elements, including solar panels, a micro-hydro turbine, an Arduino microcontroller, and a water flow sensor, which are easily accessible for the execution of the project. Although the conducted trials have shown great outcomes, there is potential for additional improvements and broadening of the system's functionality.

Renewable energy systems are pivotal in addressing global energy challenges. The integration of micro-hydro and solar photovoltaic (PV) technologies offers a promising solution for sustainable power generation. In this study, we explored the feasibility of a hybrid approach that combines these two sources in a parallel and complementary manner.

The integration of micro-hydro and solar PV in rainwater harvesting represents a promising pathway toward efficient, reliable, and environmentally friendly energy generation. Let us continue to explore innovative solutions that bridge renewable sources for a more sustainable planet.

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