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RESEARCH ARTICLE

MINIMIZING BATTERY CHARGING TIME FOR MINIHYDROELECTRIC GENERATOR VIA WATER PIPELINE

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Abstract

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Mini hydroelectric systems, with outputs up to one megawatt, have emerged as a crucial solution for decentralized and rural energy needs, providing a sustainable alternative to fossil fuels. These systems generate electricity from flowing water, offering reliable and eco-friendly power to off-grid areas. Recent advancements in mini hydropower technology focus on enhancing efficiency, reducing costs, and incorporating innovative materials and energy storage solutions. The integration of current boosters into these systems has gained attention for its potential to improve energy output and charging efficiency, further increasing their feasibility for remote applications. This study explores the design and performance of a mini hydroelectric system integrated with a current booster. The efficiency of the system was evaluated by comparing configurations with and without the booster. Circuit designs were developed and tested using Multisim software, followed by hardware validation. The results reveal that the system with the current booster significantly enhances voltage output, achieving a 43.08% increase in voltage compared to a 10.93% increase in the system without the booster. Additionally, the system with the booster showed a 307.9% improvement in efficiency, demonstrating the booster’s effectiveness in optimizing energy output. The research indicates that incorporating current boosters into mini hydroelectric systems can significantly improve their performance, making them more suitable for renewable energy applications, particularly in off-grid and remote areas. By optimizing energy conversion and storage, these systems can provide sustainable, reliable electricity, addressing the growing demand for decentralized energy solutions. Furthermore, the study investigates the design of a mini hydroelectric generator integrated with a water pipeline, aiming to minimize the charging time of a 12 V battery. The results show that while the system without a booster took over 3 hours to fully charge, the addition of the booster reduced the charging time to approximately 1 hour. This research highlights the potential of current boosters in enhancing the efficiency, scalability, and performance of renewable energy systems for real-world applications.

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Introduction:-

Mini hydroelectric systems, or hydropower projects with a maximum output of one megawatt, have emerged as a critical renewable energy solution for decentralized and rural electricity needs. These systems utilize the energy of flowing water to generate electricity, providing a reliable and eco-friendly alternative to fossil fuels. Due to their compact size and minimal environmental impact, mini hydroelectric facilities are ideal for off-grid locations and areas with limited access to conventional energy sources.

Recent advancements in small hydropower systems have focused on reducing costs, enhancing efficiency, and integrating advanced materials and technologies. Researchers have highlighted the importance of tailored design strategies for small-scale run-of-river hydropower plants to optimize energy efficiency and ensure cost-effective operation [1]. Similarly, studies have explored the role of small hydropower projects in Indonesia, emphasizing their replication potential in other developing nations and their contribution to sustainable development [2].

In addition to electricity generation, mini hydropower systems are increasingly being integrated with advanced energy storage technologies to improve grid reliability and meet variable energy demands. Research on small-scale and pico hydroelectric power systems [3] has emphasized the importance of innovative turbine designs and power electronics in enhancing system performance.

Another key approach to optimizing resource utilization is the integration of mini hydroelectric systems into existing infrastructure, such as irrigation channels and water pipelines. As global demand for renewable energy sources grows, small hydropower systems continue to demonstrate their viability as a sustainable and localized energy production option [4].

The integration of mini hydroelectric generators within water pipeline systems offers a promising solution for decentralized renewable energy generation, particularly in remote or off-grid areas [5]. These systems harness the kinetic energy of water flow within pipelines to produce electricity, which can be used for various applications, including battery charging. Efficient battery charging is vital for ensuring the reliability and effectiveness of energy storage systems, which are essential for consistent electricity supply in such setups [6].

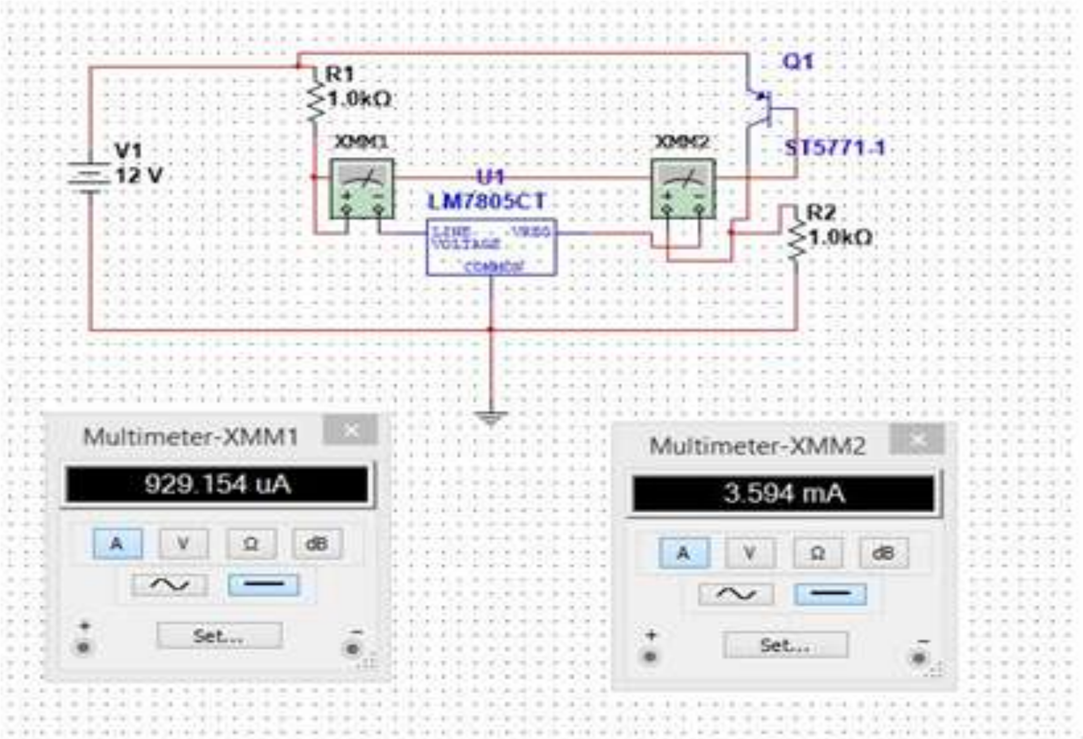
Recent research has prioritized optimizing battery charging times in mini hydroelectric systems to enhance overall energy efficiency. For instance, studies have explored small-scale hydroelectric generation techniques, emphasizing efficient energy conversion and storage mechanisms [4]. Other research has focused on integrating energy generation and storage components to minimize energy losses and improve charging times [7].

The optimization of battery charging times depends on factors such as the design of the hydroelectric generator, the characteristics of water flow within the pipeline, and the specifications of the battery storage system [8]. Innovations in turbine technology, power electronics, and energy management strategies are pivotal in achieving rapid and efficient battery charging. Addressing these aspects is essential to maximize the potential of mini hydroelectric generators in water pipeline applications, contributing to sustainable and reliable energy solutions. This paper aims to design a mini hydroelectric generator integrated into a water pipeline system, with a focus on minimizing the charging time of a 12 V battery.

Methods:-

A. Circuit Design and Simulation by using Multisim

The circuit was designed and simulated using the Multisim software. The simulation was conducted to verify that the research would achieve the expected outcomes before proceeding with the analysis of the hardware prototype.As shown in Fig. 1, the reading on multimeter XMM1 is 929.154 µA, which is lower compared to the reading on multimeter XMM2, recorded at 3.594 mA. Table 1 presents the results obtained from the initial booster circuit design.



Multimeter-XMM1

929.154 uA

Multimeter-XMM2

3.594 mA

Fig. 1:- The output of current and voltage for the first design.

Figure 2 illustrates the second design of the booster circuit, which is similar to the first design but with a modification in the switching component. The switching part has been replaced with a MOSFET model IRF540N, where the gate (G) is supplied by a function generator. The MOSFET (Metal Oxide Semiconductor Field Effect Transistor) is a semiconductor device widely used for switching and amplifying electronic signals in various electronic devices. In simple terms, when there is no voltage applied to the gate (G), the MOSFET does not conduct. The higher the voltage applied to the gate (G), the better the device conducts. To enable the MOSFET to act as a switch, toggling between open and closed states at a consistent frequency, the function generator was set to supply a frequency of 500 kHz to the gate (G). The results of the voltage booster for this design are presented in Table 2.

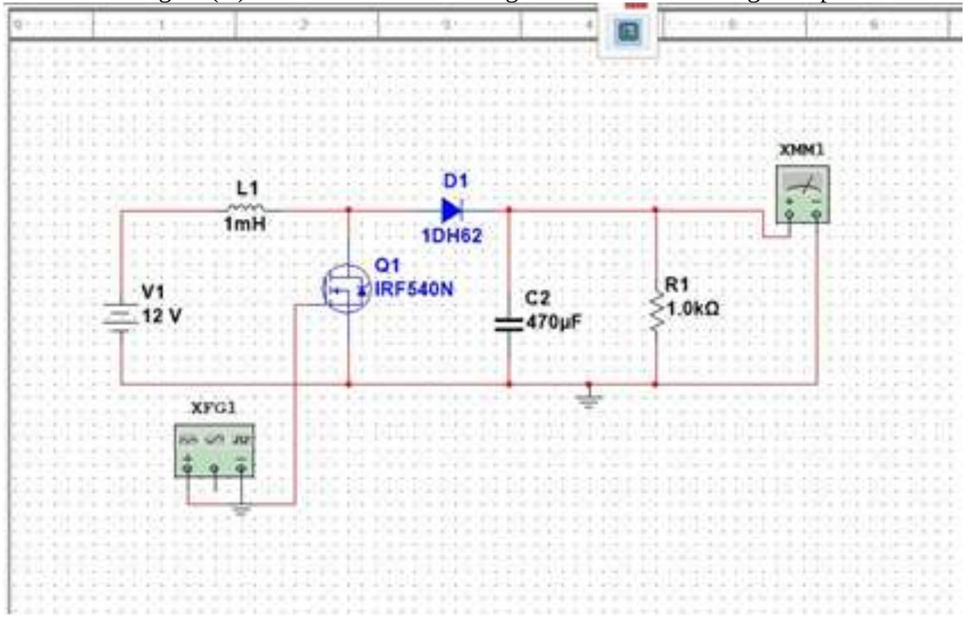


Fig. 2:- Second design of booster converter.

The third design of the booster converter, as shown in Figure 3, is almost identical to the second design, with the primary difference being the type of diode used. While the second design utilized a 1DH62 diode, this design employs a 1N4007G diode. The output voltage for this design is slightly higher compared to the second design. The results of the output voltage for this design are recorded in Table 3.

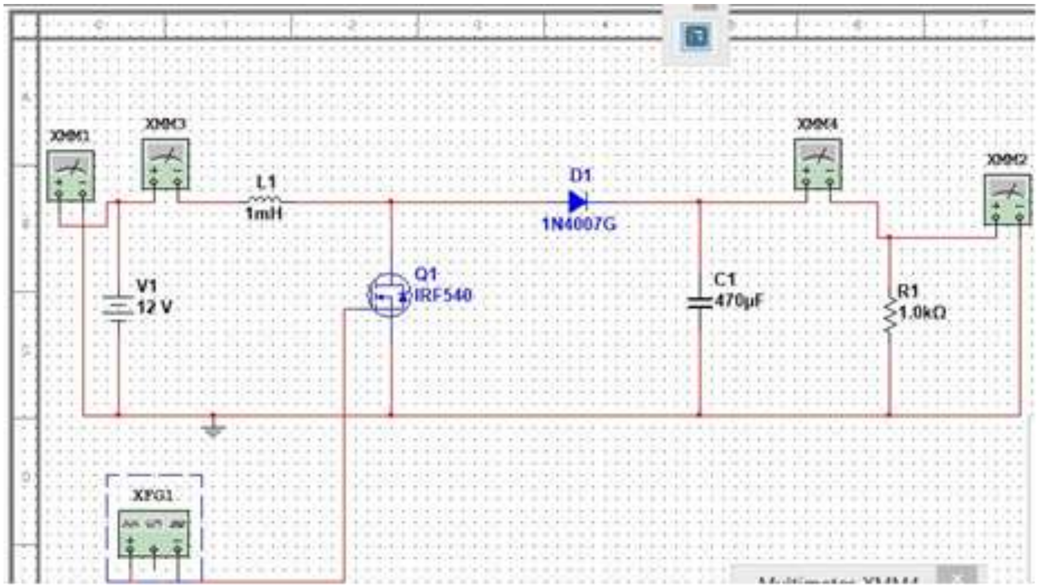


Fig. 3:- Third design of the booster converter.

B. Mini Hydroelectric

Figures 4 and 5 depict the developed mini hydroelectric system, including components such as the water flow pipelines and the stopcock valve.

Fig. 4:- Part of pipelines and the position of mini hydroelectric.

Fig. 5:- Stop clock valve view control.

During the implementation of the circuit hardware, several data points were collected as evidence to validate the results. In Fig. 6, the first data point was obtained by measuring the voltage from a standby battery through the current booster, which was recorded as 11.87 V DC. This test involved supplying power from the battery to verify that the current booster was functioning properly to produce the expected output voltage.

The output voltage generated by the current booster was then connected to an inverter to obtain an AC supply of 230 V. In Fig. 7, measurements showed that the inverter produced an output voltage of 202.5 V AC. This demonstrates that the entire system was functioning effectively based on the provided supply.

After completing all tests, the product was connected to a real pipeline system. The results showed that the output voltage generated from the generator started at 14.67 V DC, as illustrated in Fig. 8. To determine the amount of current produced by the current booster, a 12-watt LED bulb was connected to the circuit. The measurement confirmed a current of 1 A from the current booster, serving as proof of its functionality.

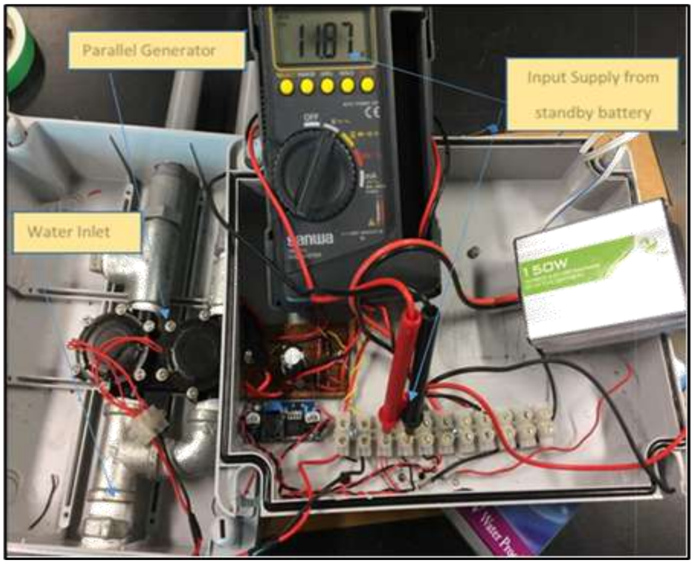


Fig. 6:- Input supply from standby battery.

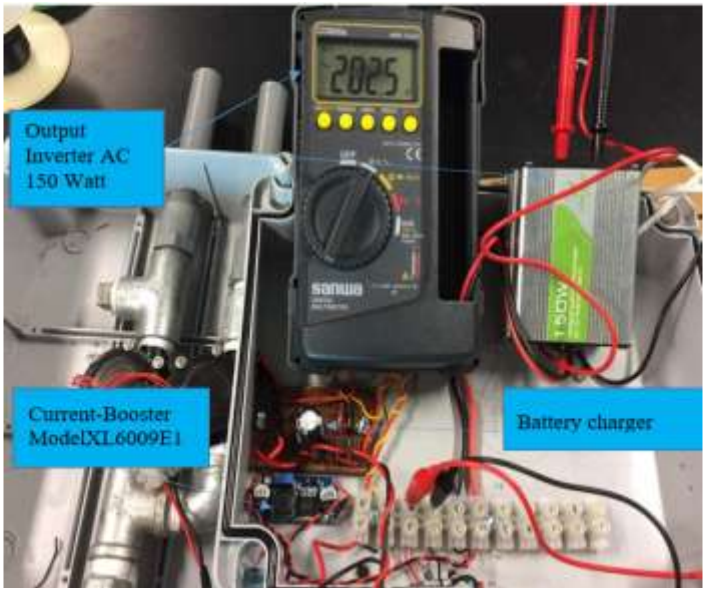


Fig. 7:- Output voltage from inverter.

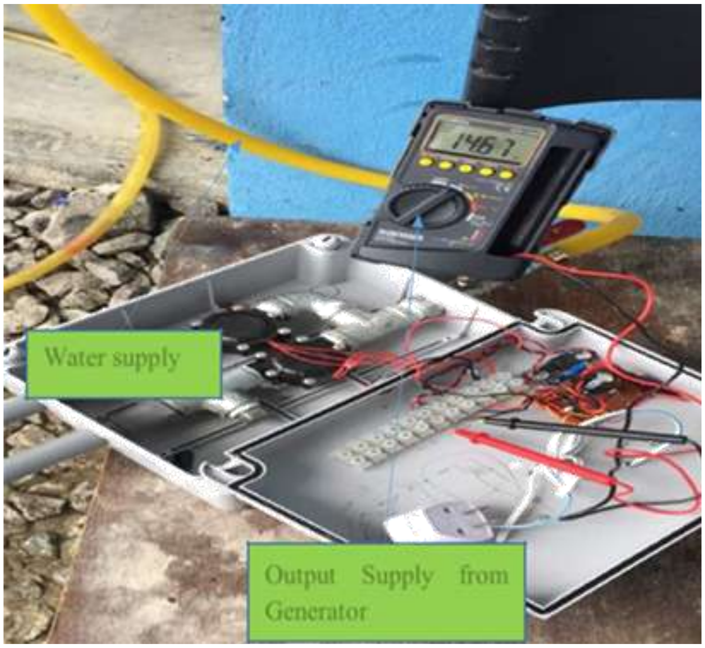


Fig. 8:- Output voltage from generator.

C. Mini hydroelectric without current booster.

Figures 9 and 10 illustrate the battery's voltage values before and after charging, both with and without the use of a current booster, highlighting the positive impact of the current booster on charging efficiency. Figure 9 shows the initial battery voltage before charging, which was 10.32 V. In this case, the battery was charged without using a current booster. As depicted in Figure 10, the battery voltage increased after being charged without the current booster. The voltage rose from 10.32 V to 11.45 V after 15 minutes of charging.

Fig. 9:- Battery voltage before charging without using current booster.

Fig. 10:- Battery voltage after charging 15 minutes without using current booster.

D. Mini hydroelectric with current booster

Figure 11 shows the battery voltage before undergoing the charging process, with an initial value of 8.13 V. The battery was then charged with a current booster integrated into the system. The voltage of the battery after charging is presented in Figure 12. As shown in Figure 12, the battery was charged for 15 minutes. The multimeter reading indicates that the battery voltage increased to 11.63 V, representing an increase of approximately 3.5 V from its initial value before charging.

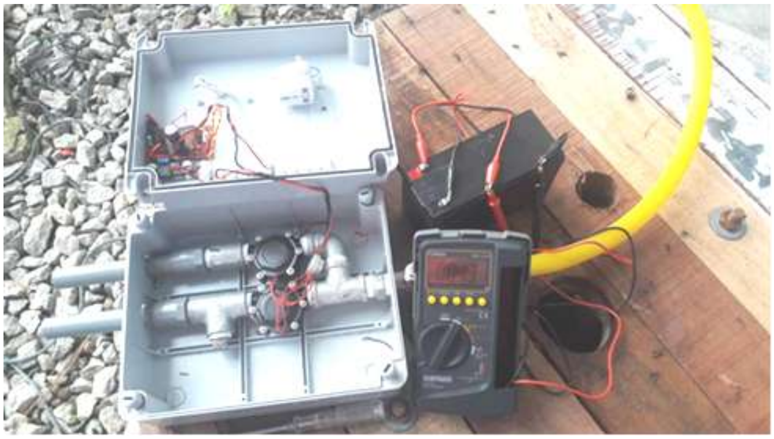


Fig. 11:- Battery voltage before charging by using current booster.

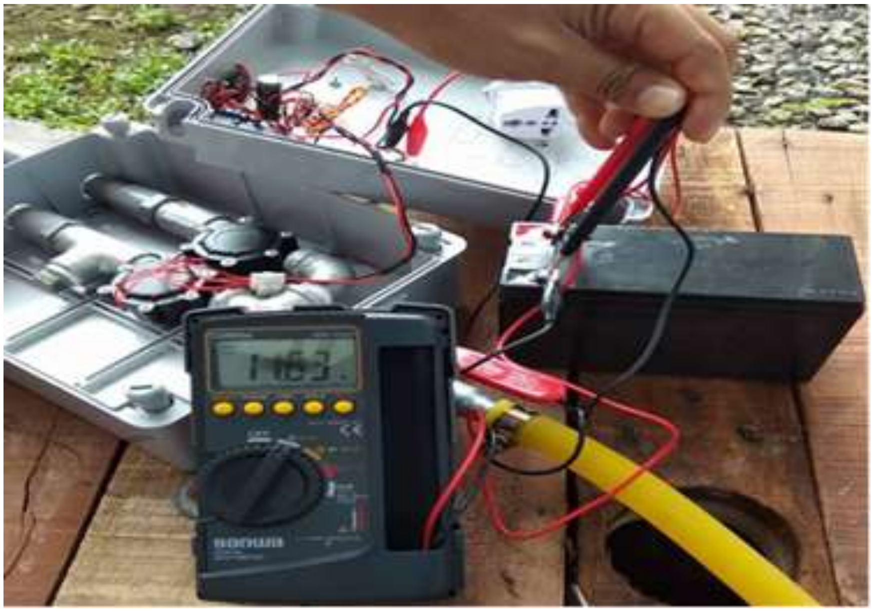


Fig. 12:- Battery voltage after charging 15 minutes by using current booster.

Resultsand Discussion:-

Table 1:- First Design.

Input Voltage (V)	Booster output voltage (V)	Booster output current (mA)
11.50	44.00	3.58
11.80	36.80	3.59
12.00	44.64	3.59
12.50	72.44	3.61
12.80	62.00	3.61
12.85	59.67	3.61
12.90	91.70	3.61
12.95	61.50	3.61
13.00	33.12	3.61
13.50	66.00	3.63

Table 2:- Second Design.

Input Voltage (V)	Booster output voltage(V)	Booster output current (mA)
11.50	30.40	364.69
11.80	31.07	375.00
12.00	31.80	381.00
12.50	32.75	398.15
12.80	33.87	408.01
12.85	34.04	409.19
12.90	34.22	411.13
12.95	34.36	413.34
13.00	34.47	414.63
13.50	35.90	428.56

Table 3:- Third Design.

11.50	32.08	522.93
11.80	33.11	530.00
12.00	33.66	545.86
12.50	35.14	567.85

12.80	36.01	581.30
12.85	36.15 0	583.21
12.90	36.30	586.07
12.95	36.41	587.05
13.00	36.58	589.93
13.50	38.00	609.72

The attached figures illustrate the differential current and voltage at the output terminal, corresponding to variations in the input voltage for each circuit design. Figure 13 presents the current output, while Figure 14 depicts the voltage output.

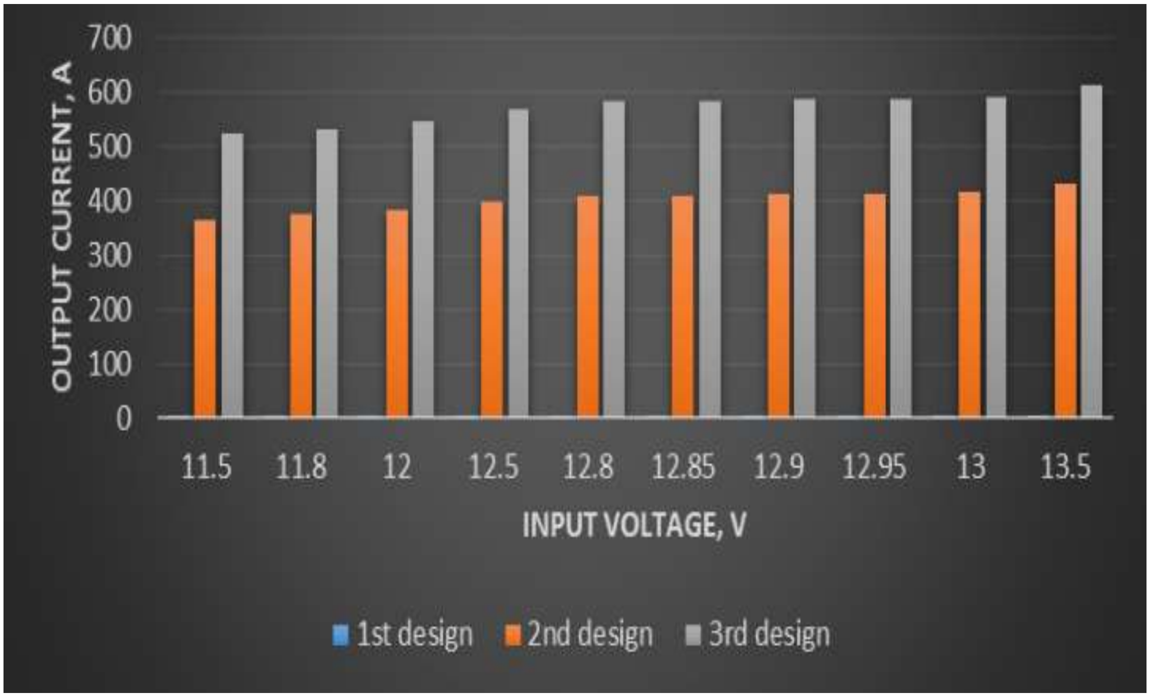


Fig. 13:- The differential of output current from different design.

Figure 13 illustrates the relationship between input voltage (V) and output current (A) for three designs: the first design, second design, and third design. Based on the data, the third design consistently demonstrates the highest output current across all input voltage levels, indicating superior performance and efficiency in current generation compared to the first and second designs. The first design generally performs better than the second design, suggesting that incremental design improvements have contributed positively to current output but still fall short of the 3rd design.

As input voltage increases from 11.5 V to 13.5 V, there is a steady increase in output current across all three designs. The third design achieves an output current exceeding 600 A at 13.5 V, showcasing its scalability and adaptability to higher input voltages. The first design shows moderate performance, with output currents consistently below the third design but maintaining a steady increase with rising input voltages. The second design lags behind the other designs, with the lowest output current across the voltage range.

The third design's significant performance lead suggests that it integrates advanced design elements or improved components that enhance current regulation and output efficiency. The consistent increase in current with voltage across all designs demonstrates that the systems are scalable and capable of handling varying energy inputs effectively.

The third design's superior output current makes it highly suitable for applications requiring high current delivery, such as energy storage systems or powering large electrical loads. The first and second designs may still be useful for lower-power applications or where cost-efficiency and simplicity are priorities.

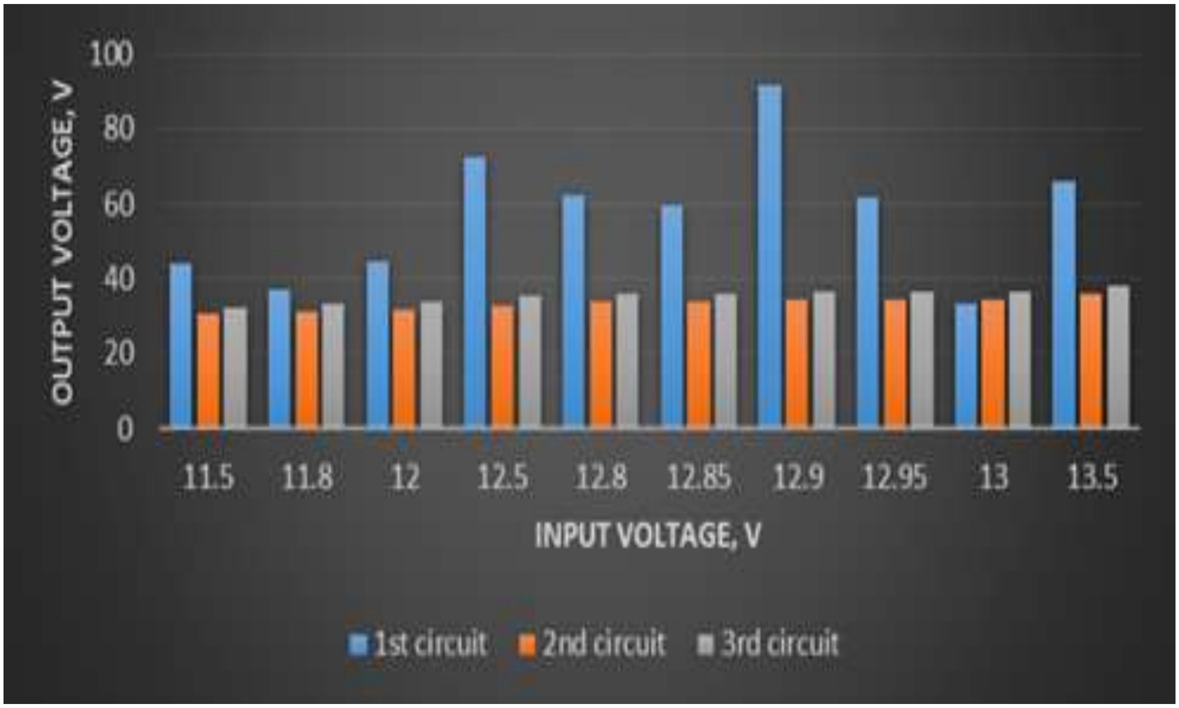


Fig. 14:- The differential of output voltage from different design.

Figure 14 illustrates the output voltage behaviour of three different circuit configurations (1st circuit, 2nd circuit, and 3rd circuit) across a range of input voltages from 11.5 V to 13.5 V.The first design consistently demonstrates the highest output voltage across all input voltage levels. At an input voltage of 12.9 V, the first design achieves a peak output voltage, indicating superior voltage boosting capability compared to the other two circuits. This highlights the potential effectiveness of the 1st circuit in applications requiring maximum voltage enhancement.

The second design shows a moderate performance, with output voltages lower than the first design but generally higher than the third design at most input voltage levels. This indicates that the second design offers a balance between performance and possibly other design parameters, such as simplicity or cost, which might make it suitable for applications where extreme voltage boosting is not required.

The third design exhibits the lowest output voltage among the three configurations across all input voltage levels. Its performance indicates limited boosting capability, suggesting it may not be the best option for applications requiring significant voltage enhancement. However, the third design may offer advantages such as lower energy consumption or better stability in certain scenarios.

For all three circuits, the output voltage generally increases with the input voltage. This trend is consistent with the expectation that higher input voltages lead to improved circuit performance. However, the first design shows a particularly pronounced improvement around 12.9 V, which may indicate an optimized operating range.

The first design's superior performance suggests it is the most suitable choice for scenarios requiring maximum energy output and efficiency, such as charging batteries in a shorter time or supporting devices with higher energy demands. The second design may be considered for applications where moderate performance suffices, and the third design could be reserved for specialized uses where simplicity or other non-performance-related factors are prioritized.

Based on the analysis, the third design is the best for battery charging performance when considering output current, as demonstrated in Figure 13. Its superior current output across all input voltage levels makes it highly effective for applications where high current delivery is critical, such as fast battery charging or powering high-demand systems. The design's scalability with increasing input voltage further reinforces its adaptability and efficiency.

The measurement for mini hydroelectric measurement is shown in Table 4.

Table 4:-Battery Voltage of Mini Hydroelectric

Type of Mini Hydroelectric	Starting Voltage (V)	Voltage after 15 minutes (V)
Without current booster	10.32	11.45
With current booster	8.13	11.63

To calculate the system's efficiency, the system with the booster is divided by the system without the booster. The calculation is as follows:

$$\text{Increasing percentage} = \frac{\text{Voltage(after} - \text{before) with current booster}}{\text{Voltage(after} - \text{before) without current booster}} 100\%$$

$$\text{Increasing percentage} = \frac{11.63 - 8.13}{11.45 - 10.32} 100\%$$

$$\text{Increasing percentage} = 307.9\%$$

The presented data evaluates the performance of a mini hydroelectric system with and without the application of a current booster. The system without the current booster demonstrated an increase in voltage from 10.32 V to 11.45 V after 15 minutes. This corresponds to an increase of approximately 10.93%. With the current booster applied, the starting voltage of 8.13 V rose to 11.63 V, resulting in an increase of 43.08%. The inclusion of the current booster amplified the voltage increase significantly compared to the system without the booster, highlighting its effectiveness in enhancing the energy output.

When comparing the two systems using the calculated efficiency, the system with the current booster achieved an increasing percentage of 307.9% relative to the system without the booster. This substantial improvement underscores the critical role of the current booster in optimizing the performance of the mini hydroelectric generator, particularly in scenarios where higher voltage output is necessary.

Both systems exhibited an increase in voltage over time, indicating their ability to generate and store energy effectively. However, the system with the current booster demonstrated a much steeper increase, likely due to the booster's ability to regulate and amplify the voltage efficiently.

The results suggest that integrating a current booster into mini hydroelectric systems can significantly enhance their performance, making them more suitable for off-grid energy solutions and renewable energy applications. The amplified voltage output with the booster ensures a more efficient energy transfer and storage process, which is essential for powering devices or charging batteries in remote areas.

Conclusion:-

This study evaluates the performance of three booster circuit designs and their impact on battery charging and mini hydroelectric systems. Based on the booster circuit design performance, the third design demonstrates the best performance in terms of output current across all input voltage levels, making it highly suitable for applications requiring high current delivery, such as fast battery charging. Based on the impact of current booster on mini hydroelectric systems, the inclusion of a current booster in the mini hydroelectric system resulted in a significant improvement in voltage output. The system with the booster demonstrated a 43.08% increase in voltage, compared to 10.93% without the booster.Efficiency calculations revealed a remarkable 307.9% improvement with the current booster, highlighting its critical role in optimizing system performance for energy generation and storage. Based on the real-world implications, the third design is recommended for high-demand applications due to its superior scalability and efficiency in current generation. The integration of a current booster significantly enhances the performance of mini hydroelectric systems, making them viable for off-grid and renewable energy applications.The findings emphasize the importance of selecting the appropriate circuit design based on specific application requirements. The third design excels in current delivery, while the first design is best for voltage enhancement. The application of a current booster in mini hydroelectric systems demonstrates significant potential for improving renewable energy technologies, ensuring efficient energy transfer and storage in sustainable energy solutions.

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