



Article Processing Dates: Received on 2024-08-07, Reviewed on 2024-11-11, Revised on 2024-11-12, Accepted on 2024-11-16 and Available online on 2024-12-30

Buck boost converter control to accelerate cooling in hydrogen system coolers

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Abstract

The electrolysis process involves decomposing water (H₂O) into hydrogen gas (H₂) and oxygen gas (O₂), requiring substantial electrical power. This study utilized an electrolyzer with a maximum capacity of 7 V and 40 A, demanding 280 watts of power. Therefore, it requires a voltage of less than 7 V but a high current of up to 40 A, as the critical parameter for the electrolyzer in producing hydrogen is the electric current flowing through it. A buck-boost converter was implemented to adjust the voltage to operate a Thermoelectric Cooler (TEC) for temperature regulation. Over time, as the electrolyzer operates and consumes a high current, there is an increase in its temperature. The system successfully maintained the electrolyzer temperature below 35°C by adjusting the output voltage between 10-14 V, with an input range of 21.62-21.65 V. The cooling system achieved a temperature reduction of 1.06°C, demonstrating its effectiveness in stabilizing the electrolyzer's performance, thus optimizing hydrogen production efficiency.

Keywords:

Buck boost converter, electrolyzer, thermoelectric control, MPPT, hydrogen system coolers.

1 Introduction

Fossil energy is still the foundation for meeting energy consumption needs in all sectors. The limited number of carbon emissions and environmental issues are factors in the increase in the atmosphere's carbon emissions. Renewable energy is an alternative to reducing fossil fuel-based energy consumption. Hydrogen energy is one of the environmentally friendly renewable energy sources [1][2]. The formation of hydrogen gas comes from the separation process of hydrogen gas (H₂) and oxygen (O₂) in water electrolysis [3].

Nomenclature: hydrogen gas (H₂), oxygen gas (O₂), water (H₂O), Thermoelectric Cooler (TEC), Maximum Power Point Tracking (MPPT), microcontroller unit (ESP32), temperature sensor (DS18B20), and Pulse Width Modulation (PWM).

Hydrogen is a cleaner energy alternative. Hydrogen is not produced freely in nature; hydrogen is made from such processes as electrolysis of water (H₂O) where it is separated between hydrogen (H₂) and oxygen (O₂). This process requires an electric current using electrodes (anode and cathode) [4]. Hydrogen and oxygen produced from the electrolysis reaction of water form

bubbles on the electrode and are then collected in a container. Several factors, namely electrode type, catalyst, temperature, and pressure, can affect the efficiency of hydrogen formation [5][6].

The current supplied to the electrolyzer is very large, which speeds up the separation process of the compound. However, this process increases the temperature of the water that circulates in the system. This increase in temperature occurs due to the current supply process at the electrode, which lasts for a long time. This results in reduced efficiency of the process of forming hydrogen gas. The temperature must be maintained at a value of 30-80 °C according to the specifications of the electrolyzer [7][8][9].

Hydrogen production increases the movement of electrons in the electrolysis process, which gets faster, so there is an increase in temperature during this process [10]. The cooling process from the external system is necessary to keep working optimally. Various cooling methods in the electrolysis process are carried out to overcome the effects of rising temperatures when the movement of electrons begins. Thermo-Electric Cooler (TEC) has not been developed much in the hydrogen production [11]. The TEC principle works based on the Peltier effect, which consists of P-type and N-type semiconductors connected to a power source and thermally connected in parallel. The working principle of TEC is when Direct Current (DC) is supplied to the Peltier element [12]. On one side, the Peltier element will be the cooling element, and on the other, it will be the heating element. On the cooling element side, it will be a cooling source for the water electrolysis system in the formation of hydrogen [13].

However, there are various ways besides using the Peltier effect in temperature conditioning in the electrolysis production process on hydrogen. The technology of high-temperature water splitting, photocatalytic water separation, and biological hydrogen is advanced for green hydrogen production [14]. Electrolysis methods of alkali, solid polymer, and oxide are methods for the production of green hydrogen in Russia [15]. Integrate adsorption cooling with an electrolyzer using a thermal collector for cooling and hot water [16].

This study is essential to explore how Peltier can be used to lower temperatures in hydrogen production processes. In addition, temperature reduction in electrolysis is still a serious problem that continues to develop. Therefore, the study aims to reduce the electrolysis process's temperature in the green hydrogen production process to control the thermo electric cooler by controlling the buck-boost converter.

2 Materials and Methods

This study utilizes a Thermoelectric Cooler (TEC) control system as an effective coolant for the water electrolysis process. During electrolysis, the temperature of the circulating water tends to rise, which can adversely affect the efficiency of hydrogen production. To mitigate this issue, the system employs a dynamic cooling mechanism, where the TEC adjusts its cooling intensity based on real-time temperature feedback. Unlike conventional cooling methods that often lack responsiveness, the proposed system integrates a buck-boost converter to optimize the voltage supplied to the TEC. This integration enables precise control of the cooling process, ensuring that the temperature remains within the optimal range specified by the electrolyzer's operating requirements, thereby enhancing overall system efficiency.

A unique feature of this study is the integration of an ESP32 microcontroller, which monitors temperature using a DS18B20 sensor and automatically adjusts the voltage supplied to the TEC. When the temperature exceeds the set point, the control system increases the supply voltage to enhance cooling. This adaptive control strategy enables a faster temperature drop, thereby maintaining system efficiency even in the presence of fluctuations in solar panel output. Additionally, the study addresses the challenge of limited cooling capacity by optimizing TEC performance through real-time voltage adjustments—an

innovative approach not widely explored in existing literature. This design not only sustains the electrolyzer's efficiency but also demonstrates scalability for larger systems, paving the way for broader applications.

2.1 Thermoelectric Cooler (TEC)

TEC is used to dissipate heat generated on the hot side. The resulting temperature will be lower if the ambient temperature equals the hot temperature. The heat-pumping process caused the function of many electrons to pass through the P-N junction.

An electric current flows on the TEC, both sides of the module will become cold due to heat absorption from the environment, and the module's hot side will be discharged. Therefore, the heat released (Qh) on the heat side equals the heat absorbed (Qc) plus the power applied to the module, as shown in Eq. 1.

$$Qh = Qc + Pin = Qc + VI \quad (1)$$

Qh is the heat released on the hot side (Watt), Qc is the heat absorbed by the cold side (Watt), and Pin is the input power of the TEC.

2.2 Buck-boost Converter

The buck-boost converter in Fig. 1 changes the amount of DC voltage. The output voltage of the buck-boost converter can be higher or lower than the input voltage [17].

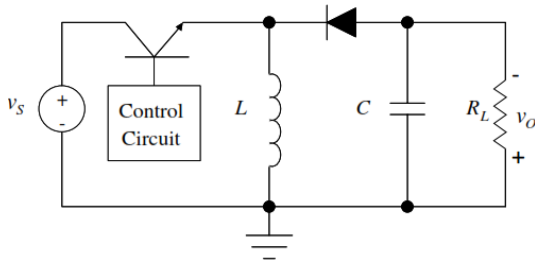


Fig. 1. Buck-boost converter.

The output voltage (Vo) can be rated using Eq. 2.

$$Vo = -Vs \left(\frac{D}{1-D} \right) \quad (2)$$

The output current (Io) can be calculated using Eq. 3.

$$Io = \frac{Vo}{R} \quad (3)$$

A buck-boost converter efficient if the input and output power are the same. Efficiency used Eq. 4.

$$\eta = \frac{Po}{Pi} \times 100\% \quad (4)$$

The duty cycle (D) value in the converter using Eq. 5.

$$D = \frac{|Vo|}{Vi+|Vo|} \quad (5)$$

To find the load resistance of the buck-boost converter, use Eq. 6.

$$R = \frac{Vo}{Io} \quad (6)$$

To find the value of the buck-boost converter inductor, use Eq. 7.

$$Lmin = \frac{(1-D)^2 \times R}{2fs} \quad (7)$$

To find the value of the buck-boost converter capacitor, use Eq. 8.

$$C = \frac{Vo \times D}{R \times fs \times \Delta V} \quad (8)$$

Pulse Width Modulation (PWM) is a signal modulation method that can regulate the active period (Ton), which has a fixed frequency at voltage. Duty cycle (D) is the ratio between the on period (Ton) and the inactivity period or zero ($Toff$). The duty cycle value can be determined using Eq. 9.

$$D = \frac{(Ton)}{Ton+Toff} = \frac{Ton}{T} = Ton \times fs \quad (9)$$

PWM signals usually have a fixed amplitude and a fixed frequency. However, the width of the pulse owned may vary. The pulse width of PWM is directly proportional to the amplitude of the original unmodulated signal. The frequency of the PWM wave is fixed, but the working cycle varies (0-100%). The PWM duty cycle is shown in Fig. 2.

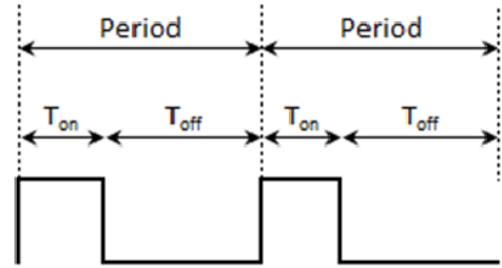


Fig. 2. Pulse width modulation.

2.3 Method

The prototype of the cooling system on electrolysis for hydrogen production using thermoelectric coolers is carried out in several stages. The initial stage begins with creating hardware and software designs.

The cooling system in electrolysis uses a feedback control configuration. The purpose of feedback control is so that buck-boost can provide output voltage as a TEC supply according to the desired temperature in the system [18][19]. This proposed cooling system approach as show in Fig. 3.

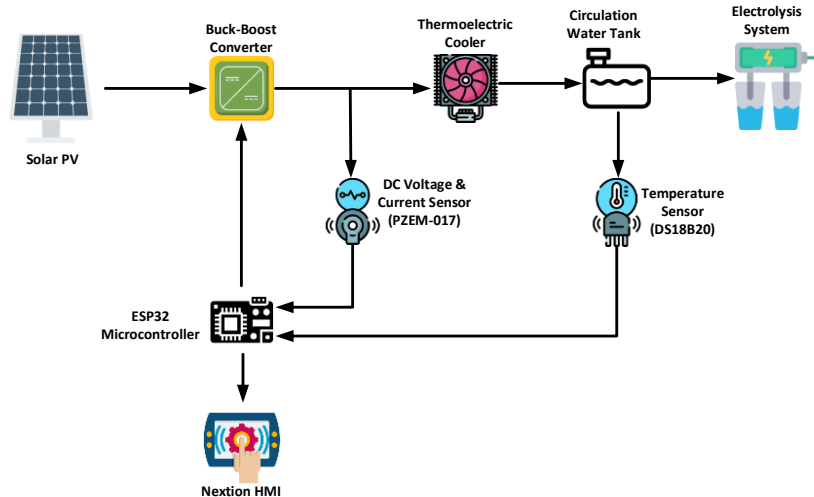


Fig. 3. Proposed approach cooling system.

Fig. 3 shows the control components of the cooling system, namely the controller, sensor, and electrolysis system. The input voltage of the TEC must be controlled when the temperature is above the set point. Conversely, the input voltage must be reduced when the temperature is below the set point.

The design of the thermoelectric control system using a buck-boost converter as a coolant has two stages. These stages are hardware design and software design. A schematic drawing of the system design in the study is shown in Fig. 4.

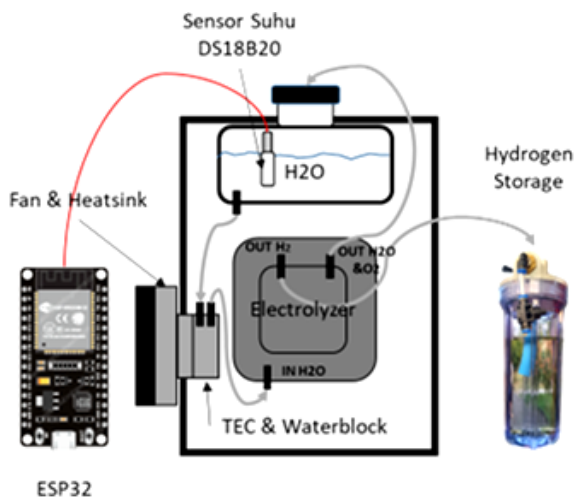


Fig. 4. Thermoelectric control circuit.

This prototype hardware implements a green hydrogen gas production plant. Green hydrogen is a type of hydrogen where the formation process in water electrolysis comes from renewable energy so that it does not cause emissions [20]. This system requires a cooling system to reduce thermal losses caused by ample current supplies over a long period. In this process, TEC will be used as a cooling device in circulating water media as raw material for hydrogen formation in electrolyzers.

This tool works because when the water temperature in the process of hydrogen formation increases, the TEC will cool the water and maintain the temperature within the desired limits. The sensor DS18B20 is measuring temperature parameters. This tool has several main tools in the water electrolysis system, including electrolyzers, pumps, TEC, hoses, hydrogen storage, fans, and heat sinks. Fig. 4 is a wiring diagram of this control system. The results of the hardware implementation as shown in Fig. 5.

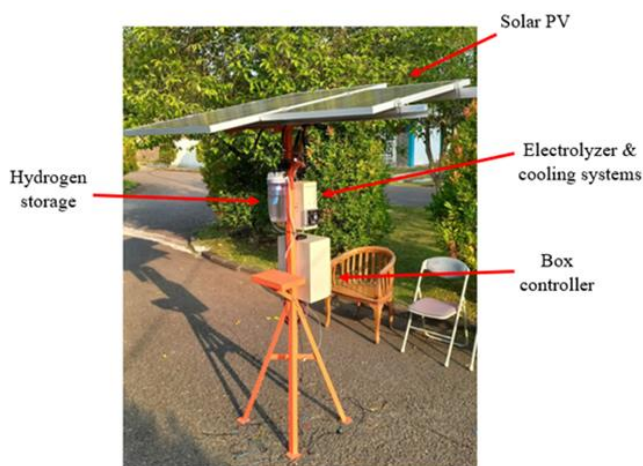


Fig. 5. Hardware architecture.

The software used in this system is Thonny, which codes the temperature control program in circulating water. The program is uploaded to the ESP32 board, and temperature, voltage, and current parameters will be monitored using HMI Nextion. The ESP32 controls the output voltage of the buck-boost converter entering the TEC with feedback from the DS18B20 sensor.

The way the programming code works is that if the temperature is less than the set point, the initial position of the servo to move the potentiometer is 90°C. If the temperature reads more than the set point and less than the set point +3, the servo angle will be at 100°C. If the temperature reads more than set point +3 and less than set point +6, then the servo angle rotates at an angle of 110°C. At the end position of the servo, the angle of the servo rotates at the 120°C position if the temperature reads more than the set point +6.

3 Results and Discussion

The results and analysis carried out several scenarios and observations from the results of the study case, namely observing the temperature value of circulating water from the cooling process using a Thermoelectric Cooler (TEC). Buck-boost converter measurement is performed without and with the load. Tests TEC input voltage conditions of 10 V, 11 V, 12 V, 13 V, and 14 V, each trial lasting 5 minutes. This voltage value is the recommended value based on the datasheet from the TEC. This TEC input voltage comes from the solar panel's output and is regulated by the buck-boost converter to get the input voltage range.

3.1 DS18B20 Sensor Validation

Testing or validation of the DS18B20 temperature sensor is carried out by comparing the results of boiling water measurements using sensors with thermometers. The test results of the DS18B20 sensor as shown in Table 1.

Table 1. Sensor validation

Temperature [°C]	Thermometer [°C]	Sensor DS18B20 [°C]
28	28	28
40	40	40.05
50	50	49.5
60	60	60.12
70	70	70
80	80	80.15
90	90	90.5

3.2 TEC Testing

TEC testing is done by varying the input voltage to determine how long it takes to get a stable water temperature based on the amount of input voltage applied. In this experiment, the voltage source comes from a net power supply with a capacity of 12 V 30 A, so the supply provided is stable, and the electrolyzer can work optimally. From the results of the measurements made, the value of decreasing water temperature using TEC as shown in Table 2.

Table 2. TEC testing

Voltage in TEC [V]	Stable temperature [°C]	Time [minute]
0	28	0
10.00	22.00	20
10.50	18.50	19
11.00	17.00	16
11.50	17.00	5
12.00	16.50	5
12.50	16.50	5
13.00	16.50	5
13.50	16.50	5
14.00	16.50	5

3.3 Buck-Boost Converter Measurement

The buck-boost converter is measured with the addition of a TEC load and without a load, which is used to determine the efficiency of the buck-boost converter. In addition, the load limit that solar panels can supply as a source of electrical power. Solar panels have a maximum voltage (V_{mp}) that must be maintained and should not be less than V_{mp} so that the efficiency of solar panels is maintained to supply electrical power to the load.

The buck-boost converter is measured with the addition of a TEC load and without a load, which is used to determine the efficiency of the buck-boost converter. The buck-boost converter input voltage comes from a 100 Wp solar panel with an open circuit voltage (Voc) of 21.8 V. When the panel is not loaded, the output voltage is 21.8 V. The buck-boost converter measurement results are in Table 3.

Table 3 explains that buck-boost input and output voltages are stable despite errors. However, the error that appears is 0.168 V for the input voltage and 0.232 V for the output voltage. This value is so small that it does not affect the performance of the buck-boost converter.

Table 3. Without load measurement

Vin [Volt]			Vout [Volt]			Servo Angle	Potentio [Ohm]
Target	Measure	Error	Target	Measure	Error		
21.8	21.63	0.17	10	10.02	0.02	90°	29.46
21.8	21.65	0.15	11	11.14	0.14	100°	33.2
21.8	21.64	0.16	12	12.25	0.25	110°	36.3
21.8	21.62	0.18	13	13.25	0.25	120°	39.65
21.8	21.62	0.18	14	14.5	0.5	130°	43.4
Average Error		0.168	Average Error		0.232		

Measuring the buck-boost converter under load conditions. Input voltage buck-boost input is kept at the maximum voltage of the solar panel (Vmp) when loaded, which is 17.8 V. When given a load, we can see a comparison between buck-boost without a load and after being given a TEC load. The measurement results of the buck-boost converter after being given a TEC load as shown in Table 4.

Table 4. With load measurement

Vin [V]	In [A]	Pin [W]	Vout [V]	Iout [A]	Pout [W]	Eff. [%]	Servo Angle
20.32	1.7	34.54	10.11	3.1	31.34	0.91	90°
20.2	2.1	42.42	11.25	3.5	39.38	0.93	100°
19.77	2.5	49.43	12.09	3.7	44.73	0.91	110°
19.28	3.1	59.77	13.18	4	52.72	0.88	120°
18.43	3.6	66.35	14.36	4.3	61.75	0.93	130°

Table 4 describes the input and output voltages of the buck-boost converter when given a TEC load. The solar panel's buck-boost input voltage is maintained above the Vmp value. The average buck-boost efficiency when given a load is 91%. The greater the electrical power TEC consumes, the more buck-boost input voltage from solar panels drops. When the load is 61.75 W, the solar panel voltage drops from 20.32 V to 18.43 V.

Data collection measures the temperature increase of circulating water as material for the electrolysis production process. In this experiment, TEC was not used as a coolant to find the temperature increase value before being given a cooling system. The experiment was conducted for 10 minutes with an electrolyzer input voltage of 4.06 V and 13.6 A, or 55.22 W. The results of these experiments were obtained by measuring the increase in circulating water temperature in a hydrogen production system based on water electrolysis, as shown in Fig. 6.

Fig. 6 shows the difference in temperature increase per minute. Average temperature increases per minute of 0.47°C. The difference in water temperature increase here will be more significant when the input power of the electrolyzer is even greater. The system is based on this because the more critical the current flows at the electrolyzer, the more heat will increase.

After operating the electrolyzer for 10 minutes, the TEC as a cooling system began to turn on, and an experiment of each input voltage of 10 V–14 V was carried out for 5 minutes. The measurement results will see how much the temperature drops every minute with different voltage levels. The results of measuring the decrease in water temperature with variations in the input voltage level given to the TEC as shown in Fig. 7.

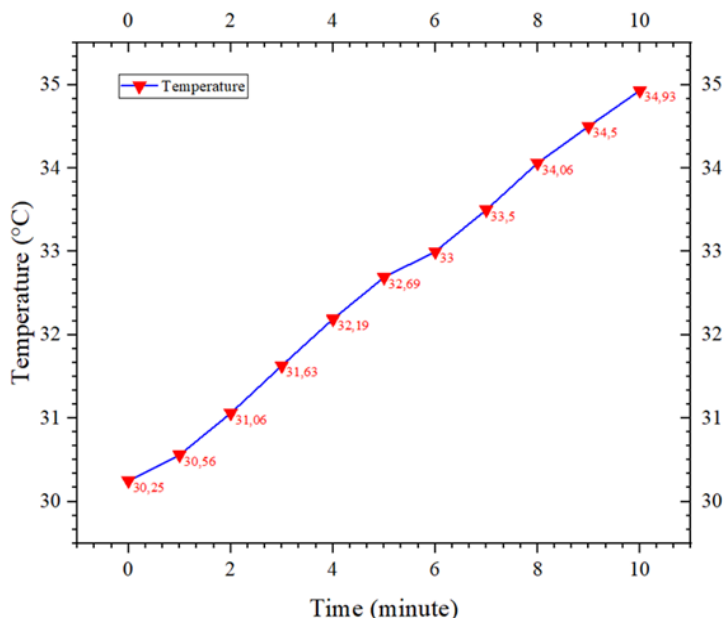


Fig. 6. Temperature increase testing.

Fig. 7 describes the electrolyzer input power of about 30.8 W; the water temperature initially increased slowly and can be lowered using TEC. The measurement shows the average temperature decreases at each TEC input voltage of 0.04°C per minute, and the water temperature fell 1.06°C from before.

TEC testing provides the input voltage from the power supply, indicating that the greater the voltage, the lower the temperature. When the TEC input voltage is 10 V, the temperature drops from the average water temperature of 34.93°C to 30.25°C within 10 minutes.

The greater the voltage applied to the TEC, the greater the power consumption used by the TEC. Buck-boost converter testing shows that the power consumption of the TEC increases as the input voltage increases. The most significant power TEC uses is 33.88 W when the input voltage is 14 V. For this reason, the input voltage must pay attention to the ability of the solar panel used.

The voltage of the solar panel to be used by TEC according to its operating voltage requires a buck-boost converter. The measurement results show that the buck-boost converter input voltage from the solar panel is 21.62–21.65 V. Changing the potentiometer's resistance value regulates the output voltage. The 10–14 V output voltage value has an average error of 0.232. The voltage value produces output according to the desired set point value when conditions have not loaded. When given a TEC load at a voltage of 13 V, the solar panel cannot supply electrical power to the load. Solar panel voltage drop occurs because the load is too large, and solar panels produce little energy. The electrical power produced from solar panels is influenced by the amount of solar irradiation and the efficiency of the solar panel.

An ample current supply influences the continuous increase in the circulating water temperature in the electrolysis system. The specifications of the electrolyzer used are 7 V 40 A, and the greater the current applied to the electrode, the hotter the electrode will be. Excessive heat can reduce the efficiency of the system. From the measurement results, circulating water increased by an average of 0.47°C per minute.

The temperature increases on the electrodes; a cooling system uses TEC with the circulating water-cooling media. The use of TEC coolant cannot reduce the temperature drastically. It takes time and voltage following the operating voltage of the TEC so that the temperature of the circulating water matches the set point. In addition, the amount of voltage supplied to the TEC must be considered so solar panels can provide electrical power. From the measurement results, the maximum voltage given can reduce the temperature by 1.06°C. This finding aligns with the results of

Ginsberg et al. (2022), who highlighted the importance of temperature control in maintaining hydrogen production efficiency [8]. As the electrical power used by the electrolyzer increases, TEC's ability to reduce temperature drop is lower. Conversely, if

the electrical power used by the electrolyzer is getting smaller, the ability of TEC to mitigate or decrease the temperature is more significant.

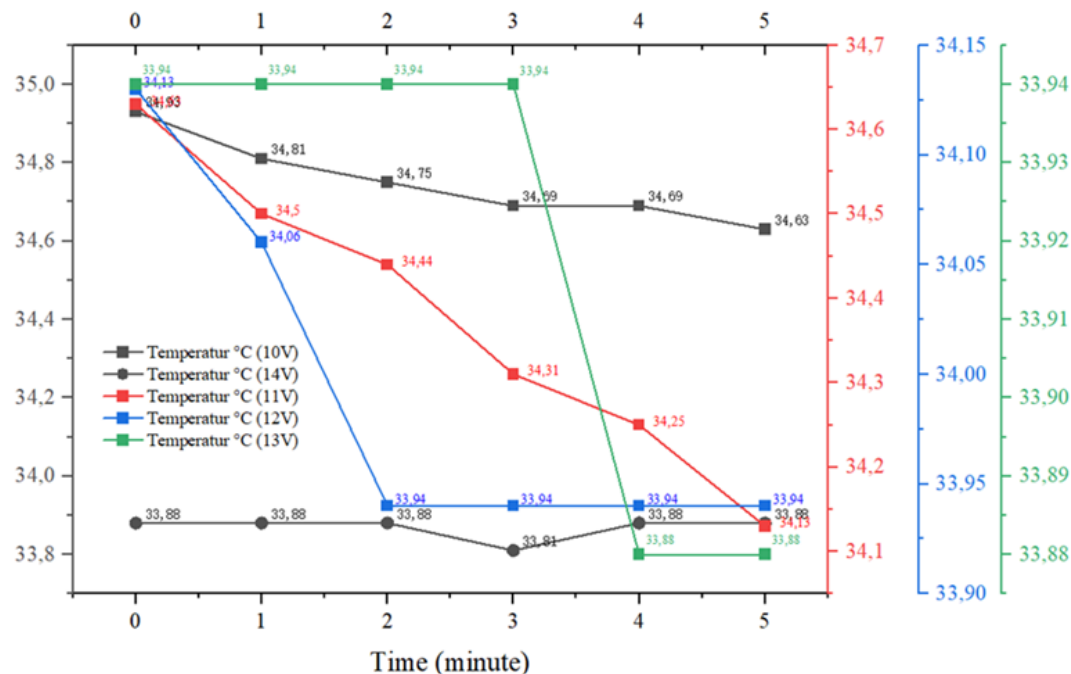


Fig. 7. Temperature decrease testing.

4 Conclusion

Over time, the operating temperature of the electrolyzer increases, as indicated by the rising temperature of the feeding water exiting the system. One approach to cooling the electrolyzer involves controlling the temperature of this water before recirculating it back into the system. However, this study does not account for the potential impact of water saturation on H₂ and O₂ production. By using a buck-boost converter to optimize the solar panel's output, the Thermoelectric Cooler (TEC) effectively maintained the system temperature below 35°C, achieving a reduction of 1.06°C. These findings demonstrate that the implemented cooling system can stabilize the electrolyzer's performance. While prior studies, such as Li et al. (2023), emphasized catalyst efficiency as a critical factor in hydrogen production, our study demonstrates that maintaining temperature stability is equally essential for achieving consistent performance in electrolyzer systems [6]. Future research should explore increasing solar panel capacity and integrating additional TEC units to enhance cooling efficiency further.

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