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Design and Development of a Modular Battery with a Battery Management System to Support the Mobility of Culinary Entrepreneurs Based on Electric Vehicles

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***Abstract*— *The use of electric vehicles as mobile culinary business platforms is becoming increasingly popular in line with the growing awareness of clean energy and operational efficiency. However, limitations in energy storage systems remain a major challenge for these entrepreneurs. This study aims to design and develop a modular battery system integrated with a Battery Management System (BMS) to support the energy needs of culinary entrepreneurs using electric vehicles. The system is designed with a modular 72V 20Ah approach, equipped with temperature, current, and voltage sensors, as well as an open-source BMS to ensure safety and efficiency. Test results show that the open-loop method could not consistently achieve the target output voltage of 15 V, requiring a 5% duty cycle adjustment, whereas the closed-loop method with PID control achieved a voltage error of less than 5%, indicating good stability against disturbances and load changes. Furthermore, the application of PID control in a Buck Converter configuration successfully reduced the voltage from 18 V to 15 V with an error of approximately 3%. Endurance test results show that the battery can power business equipment for 6 hours with a charging efficiency of 92%. From a business perspective, this product has high commercial potential with attractive profit margins. This research is expected to encourage the adoption of environmentally friendly technology in the MSME culinary sector.*

***Keywords*— *Modular Battery, Battery Management System, Buck-boost Converter, PID, MSME Culinary Sector*

I. Introduction

Electrical energy plays a vital role in the advancement of human civilization due to its versatility and ability to be easily applied and converted into various forms of energy, including storage in the form of chemical energy. To this day, the majority of electricity supply is still generated from fossil energy sources. However, the oil crisis in 2008, coupled with growing global concern over climate change, has driven many parties to seek clean energy alternatives, particularly those derived from renewable sources. To support the availability of clean energy, energy storage is essential for providing a reliable and sustainable power supply over an extended period. Batteries serve as devices for storing electrical energy that can be utilized as needed and easily transported. [1]

Batteries are one of the key devices for storing electrical energy, functioning not only as a backup power source but also enabling more efficient and structured management and monitoring of energy usage. As an essential component, batteries play a crucial role in maintaining the stability of power supply, particularly during disruptions to the main power source or in situations where the primary supply is completely unavailable. In this way, batteries help ensure the continuity of device operation, protect critical data, and maintain the smooth execution of various electricity-dependent activities, even in emergency situations or during unexpected power outages.[2]

Globally, research on battery technology for electric vehicle applications is rapidly advancing to address issues of carbon emissions and global warming. The effectiveness of electric vehicles depends on the accurate assessment of key parameters as well as the proper functioning and diagnosis of the battery storage system. [3]

In Indonesia, mobile food vendor are beginning to transition to the use of electrical energy as their primary power source. This shift is driven by the fact that electricity is more environmentally friendly and the availability of fossil fuels is steadily declining. With these advantages, electric trains are increasingly being operated today. The operation of trains is supported by many factors, one of which is signaling and telecommunication equipment. Such equipment must receive a continuous power supply to ensure safe and smooth train operations. One method of protecting the power supply is by installing batteries that function as an Uninterruptible Power Supply (UPS), serving as a backup source of stored electrical energy.[4]

However, poor monitoring and inadequate safety strategies in battery storage systems can lead to serious issues such as overcharging, over-discharging, overheating, cell unbalancing, thermal runaway, and fire hazards. To address these problems, an effective Battery Management System (BMS) plays a crucial role in enhancing battery performance, including accurate monitoring, control of charging and discharging processes, and protection of the battery from excessive temperatures. [3]

A Battery Management System (BMS) is a system consisting of hardware to measure the battery's voltage, current, and temperature in real time, as well as software to estimate the State of Charge (SOC) and State of Health (SOH). In addition, the BMS functions to monitor the voltage and temperature of each individual energy storage unit within

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the battery and to detect fault conditions such as overvoltage, over-temperature, and under-voltage. [5] To support the implementation of an effective BMS, accurate and detailed information regarding SOC and SOH is essential. SOC is a parameter that represents the ratio of the remaining energy capacity in the battery to its maximum capacity before depletion, typically expressed as a percentage. Meanwhile, SOH evaluates the overall health condition of the battery, defined as the ratio of its actual full capacity to its nominal capacity when the battery was new. A decline in SOH is often caused by repeated charging and discharging cycles, extreme temperatures, or aging, indicating a degradation in battery performance.

The estimation of SOC and SOH is typically carried out indirectly, using external parameters that can be easily measured, such as the voltage and current at the battery terminals. This is due to the limitations in directly accessing the internal chemical changes within the battery. Consequently, approaches based on external measurements have become the most commonly used methods. Careful monitoring of the battery is an essential function of the BMS to ensure that SOC and SOH are accurately tracked. Such meticulous monitoring enables the early detection of potential issues, such as significant capacity loss or unsafe operating conditions, including overcharging or deep discharge. By thoroughly understanding and continuously monitoring SOC and SOH, the BMS not only preserves battery performance but also extends its lifespan, making the system more reliable and efficient in the long term.[6]

One of the components that can be used in a Battery Management System (BMS) is a buck–boost converter. A buck–boost converter is a power conversion device that produces a DC voltage or current adjustable according to requirements. Its voltage and current source can come from a power supply or a battery, and its function is to either step down or step up the DC voltage to meet user demands.[7] A buck–boost converter is a type of DC–DC converter capable of both increasing and decreasing DC voltage through the adjustment of PWM pulse width. The proper selection of PID control constants will produce a buck–boost converter output voltage that matches the set point and provides a stable output voltage response[8]. Therefore, based on the issues described above, this research aims to optimize the management of battery energy storage systems by implementing a reliable Battery Management System (BMS). The system is designed to address challenges such as overcharging, over-discharging, and overvoltage. The main component to be developed in this study is a buck–boost converter controlled using a PID algorithm to ensure voltage and current stability. Accordingly, the author proposes the title *"Design and Development of a Battery Management System with a PID-Controlled Buck–Boost Converter for Battery Performance Optimization."* This research focuses on the development of a BMS capable of improving battery efficiency and safety, particularly to support applications in renewable energy systems or electric vehicles.

II. Methodology

This research consists of several stages, including problem identification, literature review, data collection, simulation, device implementation, validation, feasibility analysis, and conclusion.

2.1 Research Flowchart

Figure 2.1 shows the flowchart of the Battery Management System device with a Buck–Boost Converter using PID control.

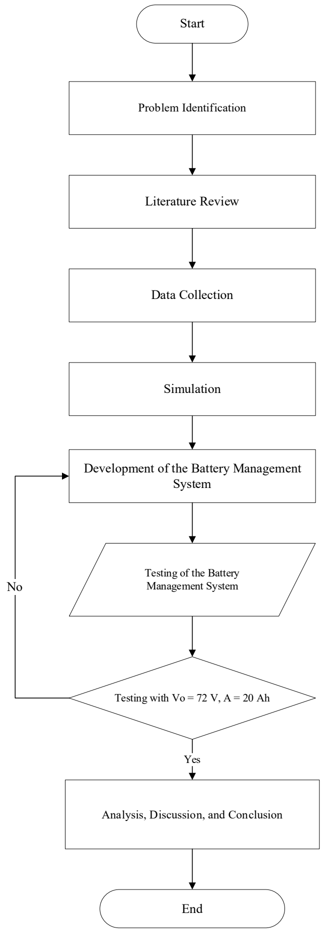

Figure 2. 1 Research Flowchart

Figure 2.1 illustrates the workflow of the system implemented in the Battery Management System with a Buck–Boost Converter using PID control.

1. Problem Identification
   Determining the main focus of the research, namely the development of an effective and efficient BMS to manage and monitor battery conditions.
2. Literature Review
   Collecting information from journals, books, and previous research to understand the concepts and technologies of BMS.
3. Data Collection
   Collecting technical data, equipment specifications, and system parameters to be used.

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4. Simulation
   Performing simulations of the BMS design to verify and validate the concept before implementation.
5. Development of the BMS Device
   Implementing the design by developing the buck–boost converter circuit, applying PID control, integrating sensors, programming the PWM, and assembling the overall system.
6. System Testing
   Testing the accuracy of the sensors, the performance of the PID control, the PWM driver, the operation of the buck–boost converter, and the overall system integration.
7. Result Verification
   The system is tested at 72 V and 10 Ah. If the results do not meet the requirements, adjustments are made and the system is retested.
8. Analysis and Conclusion
   Analyzing the test results to assess the effectiveness of the control and the performance of the BMS, and drawing conclusions.
9. Report Preparation
   All results and findings are compiled into the final research report (thesis).

2.2 Blokdiagram Sistem

The following is the system flowchart for the study entitled *"Design and Development of a Battery Management System with a PID-Controlled Buck–Boost Converter for Battery Performance Optimization"*, as shown in the figure below.

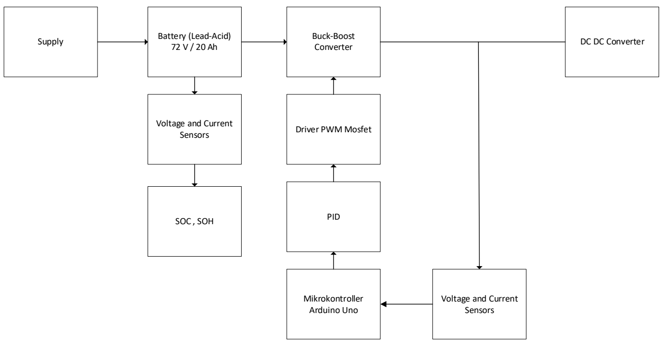

Figure 2.2 System Block Diagram

The figure above represents the flowchart of the proposed research. Figure 2.2 illustrates the block diagram of the Battery Management System (BMS) based on a Buck–Boost Converter with PID control, designed to provide a stable and efficient power supply through intelligent control and real-time monitoring.

1. Power Supply
   The main power source of the system that supplies energy to all components.
2. Battery (VRLA 72 V / 20 Ah)
   Consists of several 12 V 10 Ah batteries connected in series to form 72 V. Functions as the main energy storage.
3. SOC (State of Charge)
   Displays the remaining battery charge percentage, helping to prevent overcharging and over-discharging.
4. SOH (State of Health)
   Indicates the battery's health condition based on age, temperature, and usage cycles, and estimates the battery's remaining lifespan.
5. *Buck-Boost Converter*
   Regulates the output voltage, either stepping up (boost) or stepping down (buck) the voltage according to the load requirements.
6. Sensors (Voltage and Current)
   Monitors key parameters and sends data to the SOC, SOH, and microcontroller for analysis and control.
7. Microcontroller (Arduino Uno)
   Controls the entire system, reads sensor data, and regulates the PWM driver and converter according to the programmed logic.
8. PID Control
   Regulates the output of the Buck–Boost Converter by comparing the reference and actual values, then adjusting the control signal to maintain stability.
9. MOSFET PWM Driver
   Converts the control signal from the PID into a PWM signal to drive the MOSFET as a high-power switch.
10. Load (DC–DC Converter)
    Utilizes power from the system and performs final voltage adjustments to meet the application requirements.

2.3 Battery Specifications

Figure 2.3 Battery VRLA

A VRLA battery is a sealed lead-acid battery that is maintenance-free and safe, as it does not require liquid refilling.

Advantages:

1. Maintenance-free
2. Safe and spill-proof
3. Durable and vibration-resistant
4. Environmentally friendly
5. Stable and non-gassing

Disadvantages:

1. Heavy
2. Prone to overcharging
3. Less suitable for deep-cycle applications

Applications:

Vehicles, UPS, solar panels, heavy equipment, electric vehicles.

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TABLE 2.1 Battery Specifications

No	Specifications	Description
1	Battery VRLA	12V 20Ah
2	*Cycle use*	14.50V - 14.90V (25°C)
3	*Standby use*	13.50V - 13.80V (25°C)
4	*Initial Current*	Less than 6.0 A
5	Dimensions (Length × Width × Height)	18cm x 7,5cm x 16,5cm
6	Weight	6.5 kg

2.4 Voltage Sensor Design

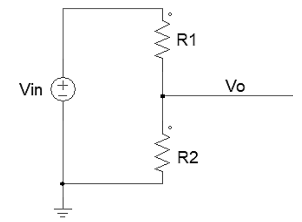

Figure 2.4 Voltage Sensor Design

Figure 2.4 illustrates the use of a voltage divider as a voltage sensor to detect Vin and Vout in the converter. This sensor converts high voltages into a 0–5 V analog signal that can be read by the Arduino Uno ADC (ATMega328, 5 V reference).

To ensure that the output voltage of the divider remains below 5 V when Vin reaches its maximum (54 V–84 V), the following formula is used:

$$V_{\text{out}} = V_{\text{in}} \cdot \frac{R_2}{R_1 + R_2}$$

Under the condition:

- V_{in}: Input voltage (54 V or 84 V).
- V_{out}: Voltage divider output (maximum 5 V).
- R_1: First resistor (given as 33 kΩ).
- R_2: Second resistor (to be calculated).

The maximum input voltage Vin is 54 V and 84 V, while the output voltage Vout is set to 5 V, which is the maximum voltage readable by the Arduino. To determine the value of resistor R1, the voltage divider formula can be used.

$$V_{out} = \frac{R_2}{R_1 + R_2} V_{in}$$

$$R_2 = \frac{R_1 \times V_{out}}{V_{in} - V_{out}}$$

$$R_2 = \frac{33k \times 5}{8.4 - 5}$$

$$R_2 = 2{,}1k\Omega$$

Therefore, the resistors to be used are R1 = 33 kΩ R2 = 2.1kΩ, ensuring that the output voltage remains within the range readable by the Arduino.

2.5 Current Sensor Design

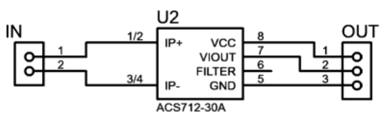

Figure 2.5 Current Sensor Design

In this final project, a single current sensor is installed on the output side of the converter. This sensor functions to detect and measure the current flowing from the converter. The measured current value is sent to the microcontroller via the ADC pin, allowing the system to monitor the output current in real-time. The sensor used is an ACS712 with a 30 A rating, chosen because the maximum output current of the converter is estimated to reach approximately 6 A, which keeps the sensor within a safe and accurate measurement range.

2.6 PWM Driver Design

Pulse Width Modulation (PWM) regulates the voltage in the buck–boost converter by varying the duration of the ON signal. The microcontroller generates a 5 V PWM signal with adjustable frequency and duty cycle. To drive the MOSFET optimally, the PWM signal is amplified using a MOSFET driver.

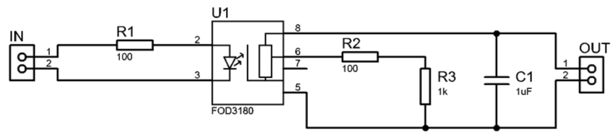

Figure 2.6 PWM Driver Design FOD3180

To protect the microcontroller generating the PWM signal from voltage spikes and noise, an FOD3180 optocoupler is used, providing galvanic isolation between the microcontroller and the power section. In the buck–boost converter, it ensures safe PWM control and can be integrated with a totem-pole driver to enhance gate drive current for efficient high-frequency switching. Figure 2.6 shows the PWM driver schematic, consisting of three terminal pairs, two resistors (100 Ω and 10 Ω), one 0.1 µF capacitor, and the FOD3180.

2.7 Buck–Boost Converter Design

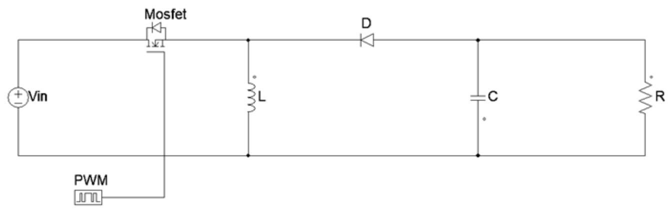

Figure 2.7 Buck–Boost Converter Design

The Buck–Boost Converter circuit is designed using MOSFETs as switches to step down the voltage (buck mode) or step up the voltage (boost mode) by adjusting the PWM duty cycle generated by the microcontroller. The Buck–Boost Converter is used to stabilize the battery output voltage, which is expected to reach 72 V. The design of the Buck–Boost Converter includes the calculation of its components and the overall circuit configuration, as detailed in Table 2.2.

TABLE 2.2 Buck–Boost Converter Calculation Parameters

Minimum input voltage (Vin,min)	54 V
Maximum input voltage (Vin,max)	84 V
Output voltage (Vout)	72 V
Output voltage ripple (ΔVout)	0.1% = 0.072 V
Inductor current ripple (ΔIL)	1% = 0.1 A
Output current (Io)	10 A

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Frequency (F)	100 Khz
Duty Cycle (D)	0.5714 & 0.4615
Inductor (L)	193 mH
Capacitor (C)	1000 uF
Resistor (R)	100Ω

III. Results and Analysis

This section presents the testing process and discussion for the study on the Design and Development of a Battery Management System with a PID-Controlled Buck–Boost Converter.

3.1 Voltage Sensor Calibration

The voltage sensor testing was conducted by applying an input voltage corresponding to the actual voltage to be measured by the sensor. In the Buck–Boost Converter, two voltage sensors were used, each placed on the input and output sides of the converter. Therefore, the testing was performed twice, once for each sensor. The circuits for the input and output voltage sensors are shown in Table 3.1.

TABLE 3.1 Test Results of Input Voltage Sensor

Vin (V)	ADC (Bit)	Vo Sensor (V)	Vo Teori (V)	*Error* (%)
0	0	0	0	0%
2	13	0,0789	0,075	4,86
4	30	0,1499	0,150	0,39
6	45	0,2209	0,226	2,14
8	62	0,2961	0,301	1,62
10	76	0,3748	0,376	0,37
12	90	0,445	0,451	1,43
14	106	0,516	0,527	2,03
16	122	0,591	0,602	1,81
18	137	0,665	0,677	1,80
20	153	0,741	0,752	1,52
22	168	0,811	0,828	2,01
24	183	0,889	0,903	1,54
26	198	0,965	0,978	1,34
28	214	1,034	1,053	1,84
30	230	1,116	1,129	1,12
32	245	1,185	1,204	1,57

Table 3.1 shows the test data of the input voltage sensor. To verify the accuracy of the obtained data, theoretical calculations are required. Below is a sample of the theoretical calculation for the sensor output voltage going to the ADC pin of the microcontroller, along with the corresponding error values:

- Given :
  $Vin = 10\ V$
  $R1 = 1290\ \Omega$
  $R2 = 33000\ \Omega$
- Asked :
  $Vout(Theoretical)?$
- Answer :

$$V_{out} = \left(\frac{R_1}{R_1 + R_2}\right) \times V_{in}$$
$$= \left(\frac{1290}{1290 + 33000}\right) \times 10$$
$$= 0{,}376\ V$$

After obtaining the theoretical sensor output voltage, the next step is to calculate the error between the practical sensor output and the theoretical value. The following is a sample calculation of the error (Vin = 10 V):

- Given :
  $Vout\ Practical = 0{,}3748$
  $Vout\ Theoretical = 0{,}376$
- Asked :
  $Error\ Value?$
- Answer :

$$\text{Error} = \left|\frac{V_{out\ theoretical} - V_{out\ practical}}{V_{out\ theoretical}}\right| \times 100\%$$
$$= \left|\frac{0{,}376 - 0{,}3748}{0{,}376}\right| \times 100\%$$
$$= 0{,}37\%$$

Based on Table 3.1, it can be seen that the correlation between the input voltage and the ADC output produces a linear characteristic with a proportional relationship. The test data were further analyzed using the linear regression method to obtain a mathematical relationship between the involved variables. In this experiment, there are two main variables: the ADC value (Y) as the independent variable and the input voltage Vin (X) as the dependent variable. A graphical representation of the relationship between the voltage values and the ADC readings is presented in Figure 3.1.

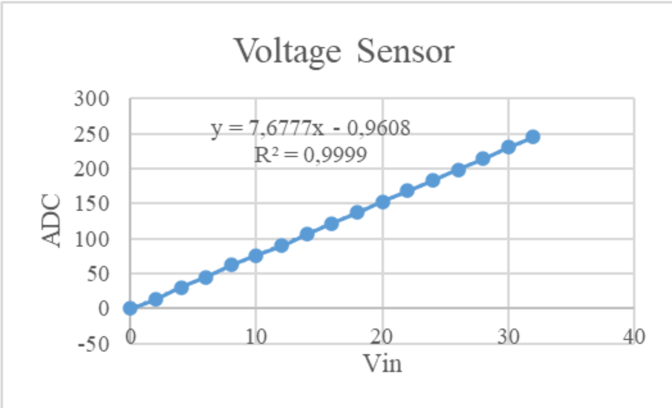

Figure 3.1 Linear Equation Graph of the Input Voltage Sensor

Based on the voltage sensor test results, it can be concluded that the sensor exhibits good linearity with a stable voltage response. This quality ensures that data processing in the microcontroller can proceed consistently and reliably. The graph shown in Figure 3.1 presents the obtained mathematical equation, where the output voltage sensor of the converter has the equation y = 7,6777x - 0,9608. In the implemented program, the variable x represents the voltage in volts, while the variable y corresponds to the ADC reading obtained from the microcontroller.

3.2 Current Sensor Calibration

In this system implementation, the current sensor used is the ACS712 with a 30 A rating. The current sensor is placed on the output path of the converter to monitor the output current. The ACS712-30A was selected based on the need to

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measure higher maximum currents in accordance with the system specifications. The current sensor testing was conducted by connecting the component in series with a variable resistor load to obtain a range of measurable current values. The results of the current sensor characterization are presented in Table 3.2, showing the correlation between the actual current and the sensor readings.

TABLE 3.2 Test Results of the ACS712-30A Current Sensor

Iin (I)	ADC (Bit)	Vout (mV)	V Teori (mV)	*Error* (%)
0	512	0	0,0	0
0,1	508	0,3	0,3	1,00
0,2	507	0,7	0,8	7,60
0,3	505	0,9	0,9	1,00
0,4	504	1,3	1,4	4,67
0,5	502	1,7	1,8	6,50
0,6	500	2	2,1	5,71
0,7	498	2,4	2,6	6,82
0,8	496	2,6	2,7	4,67
0,9	493	3	3,2	5,71
1	491	3,2	3,3	4,00
1,1	489	3,5	3,6	3,75
1,2	487	4	4,2	5,71
1,3	484	4,2	4,4	4,41
1,4	481	4,5	4,7	4,19
1,5	479	4,8	5,0	4,00
1,6	477	4,9	5,0	2,00
1,7	476	5,1	5,2	1,00
1,8	473	5,4	5,5	1,00
1,9	471	5,7	5,8	1,00
2	469	6	6,1	1,00

Table 3.2 presents the test data of the current sensor. To verify the accuracy of the obtained data, a comparison with theoretical calculations is required. Below is a sample of the theoretical calculation for the sensor output voltage sent to the ADC pin of the microcontroller, along with the corresponding error values:

- Given :
  Iin = 2A
  Sensor Sensitivity = 0,66 mV
- Asked :
  Vout (*Theoretical*)?
- Answer :

$$V_{out} = \frac{V_{Practical} - I_{in}}{\text{Sensor Sensitivity}} = \frac{6 - 2}{0{,}66} = 6{,}1 \text{ mV}$$

After obtaining the theoretical output voltage of the current sensor, the next step is to calculate the error between the practical sensor output and the theoretical value. The following is a sample calculation of the error (Iin = 2 A):

- Given :
  Vout Practical = 6 mV
  Vout Theoretical = 6,1 mV
- Asked :
  Error Value?
- Answer :

$$\text{Error} = \left|\frac{V_{out\,theoretical} - V_{out\,practical}}{V_{out\,theoretical}}\right| \times 100\% = \left|\frac{6 - 6{,}1}{6}\right| \times 100\% = 1\%$$

Table 3.2 shows that there is a linear relationship between the input current and the ADC output value, forming a curve with a directly proportional trend. The test data need to be further analyzed using linear regression to obtain the functional relationship between two or more variables. In this experiment, there are two main variables: the ADC value (X) as the independent variable and the sensor current (Y) as the dependent variable. The graph illustrating the relationship between the current values and the ADC readings is shown in Figure 3.2.

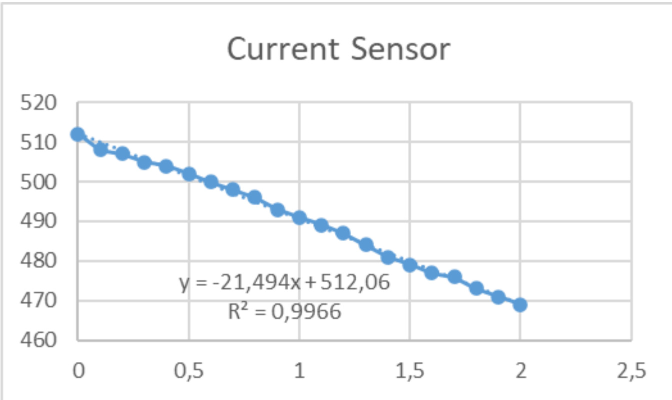
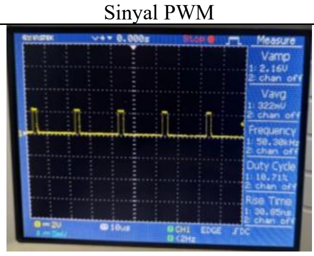
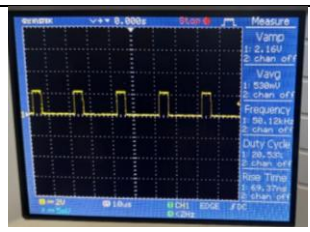


Figure 3.2 Linear Equation Graph of the Current Sensor

3.3 *PWM Signal Calibration*

The PWM signal testing was conducted to ensure that the signal used as input to drive the MOSFET switching has the correct frequency. In the Buck–Boost Converter, the switching frequency used is 50 kHz.

TABLE 3.3 PWM Signal Image

Duty Cycle	Sinyal PWM	Vout (V)
0,1		2.289V
0,2		4.065V

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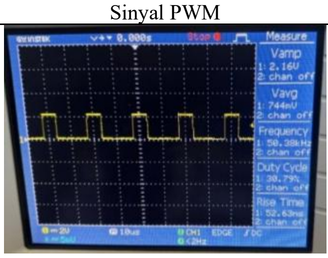
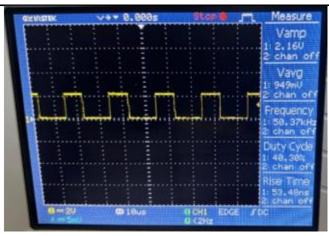
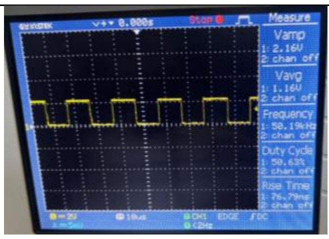
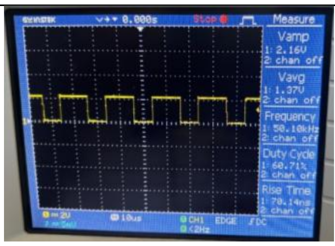
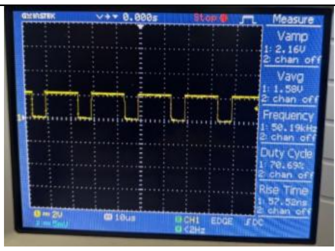
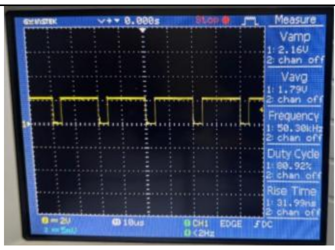
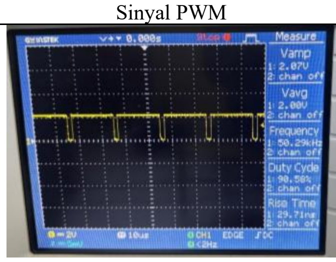
Duty Cycle	Sinyal PWM	Vout (V)
0,3		6.37V
0,4		8.38V
0,5		10.46V
0,6		12.47V
0,7		14.47V
0,8		16.55V
0,9		18.56V

Based on Table 3.3, the MOSFET driver circuit has functioned properly. For example, at a duty cycle of 0.8, the theoretical output voltage from the MOSFET driver is 80% × 21 V = 16.8 V, while the test result shows a voltage of 16.55 V. Figure 3.1 illustrates the MOSFET driver circuit design, which acts as an isolator between the Buck–Boost Converter and the microcontroller. This circuit plays an important role in preventing damage caused by the bidirectional current flow from the Buck–Boost Converter to the microcontroller.

3.4 Inductor Value Calibration

In the design of the Buck–Boost Converter for this system, a single inductor is used as the main component for energy storage and current regulation. The use of a single inductor was chosen for space efficiency and circuit simplification without compromising system performance. The inductor was tested using an LCR meter model LCR700 to verify that the inductance value met the design specifications. According to the initial design, the expected inductance value was 193 μH. Measurement results at a frequency of 100 kHz showed an actual inductance of 192.17 μH with a quality factor of 193.9.

Figure 3.3 Inductance (L) and Quality Factor (Q) Testing

From the test results, there is a difference of 0.83 μH, or approximately 0.43%, from the planned value. This level of accuracy indicates that the inductor manufacturing process aligns with the initial design specifications and remains within an acceptable tolerance for practical applications, where inductor components typically have a tolerance of ±5% to ±20%. The measurement results being close to the theoretical value suggest that design parameters such as the number of turns, core material, and winding geometry were appropriately selected.

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3.5 Battery Testing

The testing was conducted on a 12 V battery with a nominal capacity of 20 Ah (MS20-12) using a constant load of 1,4 A. The purpose of this test was to estimate the State of Charge (SOC) using the Coulomb Counting method and to determine the State of Health (SOH).

TABLE 3.4 Test Results of 12 V 20 Ah Battery

Timestamp	SoC (%)	Voltage (V)	Current (A)
13:20:38	100%	13,30	1,4
13:29:09	99%	13,25	1,4
13:37:43	98%	13,19	1,4
13:46:18	97%	13,14	1,4
13:54:52	96%	13,08	1,4
14:03:26	95%	13,03	1,4
14:12:01	94%	12,97	1,4
14:20:35	93%	12,92	1,4
14:29:09	92%	12,86	1,4
14:37:43	91%	12,81	1,4
14:46:18	90%	12,76	1,4
14:54:52	89%	12,70	1,4
15:03:26	88%	12,65	1,4
15:12:01	87%	12,59	1,4
15:20:35	86%	12,54	1,4
15:29:09	85%	12,48	1,4
15:37:43	84%	12,43	1,4
15:46:18	83%	12,37	1,4
15:54:52	82%	12,32	1,4
16:03:26	81%	12,27	1,4
16:12:01	80%	12,21	1,4
16:20:35	79%	12,16	1,4
16:29:09	78%	12,10	1,4
16:37:43	77%	12,05	1,4
16:46:18	76%	11,99	1,4
16:54:52	75%	11,94	1,4
17:03:26	74%	11,88	1,4
17:12:01	73%	11,83	1,4
17:20:35	72%	11,78	1,4
17:29:09	71%	11,72	1,4
17:37:43	70%	11,67	1,4
17:46:18	69%	11,61	1,4
17:54:52	68%	11,56	1,4
18:03:26	67%	11,50	1,4
18:12:01	66%	11,45	1,4
18:20:35	65%	11,39	1,4
18:29:09	64%	11,34	1,4
18:37:44	63%	11,29	1,4
18:46:18	62%	11,23	1,4
18:54:52	61%	11,18	1,4
19:03:26	60%	11,12	1,4
19:12:01	59%	11,07	1,4
19:20:35	58%	11,01	1,4
19:29:09	57%	10,96	1,4
19:37:44	56%	10,90	1,4
19:46:18	55%	10,85	1,4
19:54:52	54%	10,80	1,4
20:03:26	53%	10,74	1,4
20:12:01	52%	10,69	1,4
20:20:35	51%	10,63	1,4
20:29:09	50%	10,58	1,4
20:37:44	49%	10,52	1,4
20:46:18	48%	10,47	1,4
20:54:52	47%	10,41	1,4
21:03:26	46%	10,36	1,4
21:12:01	45%	10,31	1,4
21:20:35	44%	10,25	1,4
21:29:09	43%	10,20	1,4
21:37:44	42%	10,14	1,4
21:46:18	41%	10,09	1,4
21:54:52	40%	10,03	1,4

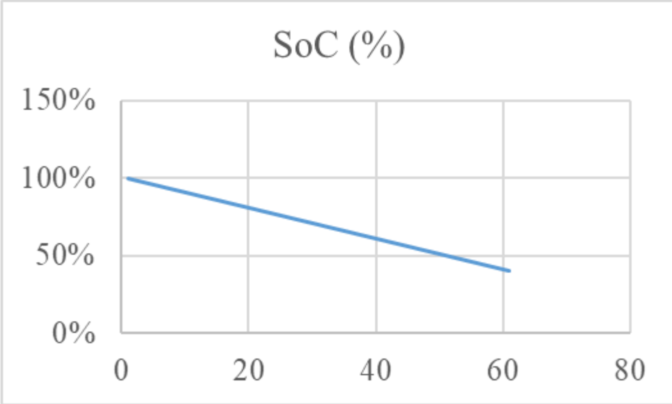

Figure 3.4 Graph of State of Charge (SOC) Percentage

The battery's State of Charge (SoC) decline was observed during the discharging process with a constant current of 1.4 A. Measurements were taken from 13:20:38 to 21:54:52, approximately 8 hours and 34 minutes. Based on the collected data, the SoC consistently decreased from 100% to 40%, with an average drop of 1% every 9 minutes. This decline pattern is linear, reflecting a stable discharge current without additional load or significant fluctuations. During the discharging process, the battery voltage gradually decreased from 13.30 V to 10.03 V.

TABLE 3. 5 Battery Test Parameters

Parameter	Nilai
Tegangan awal	13,3 V (SOC 100%)
Tegangan akhir	10,3 V (SOC 40%)
Arus beban	1,4 A
Ampere-jam (Ah).	1Ah = 1A × 3600 s = 3600 Coulomb
Durasi Total	8 jam 34 menit 14 detik = 30.854 detik

The test results indicate that the Coulomb Counting method can be used accurately to estimate the SOC. The estimated final SOC value of 40.01% based on current integration is highly consistent with the final voltage value of 10.03 V. During the test, which lasted over 8.5 hours with a constant 1.4 A load, the battery was able to deliver 11.998 Ah, equivalent to approximately 60% of its total capacity. The estimated actual full capacity (SOH) reached 99.98%, indicating that the battery remains in very good condition.

3.6 Buck–Boost Converter Testing with Target Output Voltage Vo = 15 V

The Buck–Boost Converter testing was conducted using a variable resistor load of 100 Ω, allowing manual adjustment of the load. The input voltage source was provided by a DC power supply that delivers a stable voltage, adjustable as needed for testing. The main objective of this test was to evaluate the performance and characteristics of the Buck–Boost Converter under varying input voltages. In this testing, a target output voltage of 15 V was set, requiring the duty cycle to be gradually adjusted to achieve this voltage. The testing process was carried out systematically to observe the converter's response under different input conditions. The results of this test are presented in Table 3.6.

TABLE 3.6 Buck–Boost Converter Test Results with Target Output Voltage Vo = 15 V

Vin (V)	Duty	Vo (V)	Vo LCD (V)	Vo Target (V)	*Error* (%)
10	0,58	15,32	15	15	2,13
11	0,56	15,41	15	15	2,73
12	0,54	15,57	15,6	15	3,80
13	0,52	15,64	15,4	15	4,27
14	0,5	15,64	15,4	15	4,27
15	0,48	15,35	15	15	2,33
16	0,46	15,34	15	15	2,27
17	0,44	15,48	15,2	15	3,20
18	0,42	15,54	15,3	15	3,60
19	0,39	15,49	15,3	15	3,27
20	0,36	15,59	15,3	15	3,93
Rata - Rata					3,25

3.7 PID Control Testing

The testing of the Buck–Boost Converter aimed to evaluate the performance of the system controlled using PID control. The test was conducted by varying the input voltage of the converter while setting the output set point at 15 V. The objective was to observe the ability of the Buck–Boost Converter to maintain a stable output voltage despite changes in input voltage, with the duty cycle adjusted automatically by the PID system. Using PID parameters of Kp = 0.2, Ki = 0.014, and Kd = 0.0025, the converter was tested to evaluate the system's response to input voltage variations with a target output of 15 V. These parameters control the duty cycle to ensure that the output voltage remains stable at the reference value. The use of PID control allows the converter to respond more accurately to input changes, minimize steady-state error, and reduce overshoot. Test results indicate that the system can maintain stable output voltage with errors within acceptable limits, as shown in Table 3.7.

TABLE 3.7. Buck–Boost Converter Test Results with PID Control

Vin (V)	Duty	Vo (V)	Vo LCD (V)	Vo Target (V)	*Error* (%)
10	0,4	15,54	15,11	15	3,60
11	0,36	15,37	15,11	15	2,47
12	0,33	15,4	15,11	15	2,67
13	0,3	15,44	15,11	15	2,93
14	0,28	15,39	15,11	15	2,60
15	0,26	15,52	15,11	15	3,47
16	0,25	15,38	15,11	15	2,53
17	0,22	15,5	15,24	15	3,33
18	0,21	15,45	15,24	15	3,00
19	0,2	15,42	15,5	15	2,80
20	0,19	15,47	15,11	15	3,13
Rata - Rata					2,96

Figure 3.5 & 3.6 illustrates the performance of the buck–boost converter under PID control for two input voltage conditions: 10 V and 20 V, with a target output voltage of 15 V. At Vin = 10 V (boost mode), the output voltage approaches 15 V, with minor ripple occurring after approximately 50 ms, indicating that the PID controller continuously adjusts the control signal to maintain stability. At Vin = 20 V (buck mode), the output voltage is also regulated near 15 V, exhibiting smaller fluctuations compared to the boost mode, which demonstrates a more stable system response. Both conditions show a brief initial overshoot before reaching steady-state, a typical characteristic of closed-loop control systems. Overall, the graph confirms that the PID parameters (Kp = 0.2, Ki = 0.014, Kd = 0.0025) effectively maintain the output voltage near the set point despite variations in input voltage.

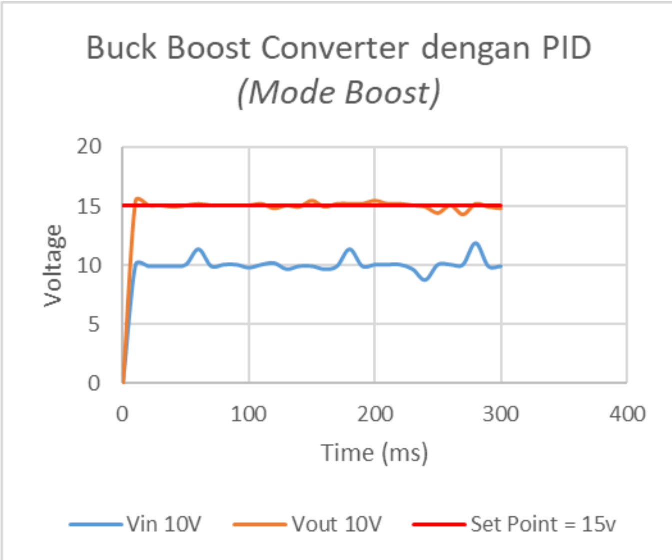

Figure 3.5 Output Voltage Response in Boost Mode with PID Control

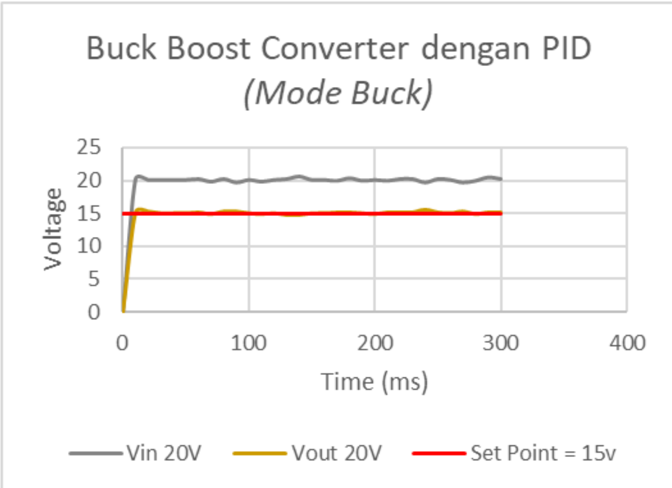

Figure 3.6 Output Voltage Response in Buck Mode with PID Control

IV. Conclusion

This project involved planning, assembly, testing, and data collection to develop a Battery Management System (BMS) with a buck–boost converter controlled by PID.

The designed BMS successfully stabilizes the battery voltage, producing 15 V from an input range of 10–20 V. Test results show good performance and stability, especially under PID control, indicating that the system ensures safe and reliable battery operation.PID control proved effective in maintaining output voltage despite input fluctuations. With parameters Kp = 0.2, Ki = 0.014, and Kd = 0.0025, the system

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achieves a rise time of ~10 ms, overshoot of ±3%, settling time of ~40 ms, and a steady-state error of around 3%.

In conclusion, PID-controlled buck–boost conversion outperforms the open-loop method in voltage accuracy and overall system stability.

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