

Output voltage control of Multi Input Boost Converter based on Proportional Integral (PI) controller

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ABSTRACT

The design and implementation of a Multi Input Boost Converter (MIBC) based on Proportional-Integral (PI) control is discussed in this study to ensure output voltage stability in the face of load variations and input source fluctuations. Two DC input sources are integrated into the system architecture to produce a larger and more consistent output voltage. An Arduino Mega 2560 is used to create the PI controller, which is programmed using MATLAB/Simulink and employs PWM signal duty cycle settings to control the MOSFET in the converter circuit. Variability in input, load, and voltage setpoint are factors that influence experimental results. By comparing experimental results with a system without control, it is proven that PI control can eliminate overshoot and voltage ripple, reduce steady-state error, and maintain the output voltage close to the reference value. Additionally, in various test configurations, the system demonstrates good stability and fast response time. Therefore, MIBC with PI control can be used to improve the efficiency and reliability of multi-input power conversion, which can be beneficial for renewable energy systems requiring a stable DC power source.

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1. INTRODUCTION

As the world's population grows, industries become more developed, and technology advances, so does the demand for electrical energy [1]. On the other hand, fossil fuels, which have historically been the main source of electricity generation, are rapidly running out of supply and having a major negative influence on the environment [2]. In order to fulfill future energy demands, renewable energy sources like photovoltaic (PV) systems, wind turbines, and battery-based storage have become competitive options [3]. However, maintaining a steady and dependable power supply is difficult for both grid-connected and standalone applications due to the intrinsic intermittency and unpredictability of these sources, which are brought on by variations in solar irradiation, wind speed, and other environmental conditions[4].

Power conversion systems are essential for controlling and stabilizing the output voltage supplied to loads in order to solve this problem. The Boost Converter is one of the most used converter topologies for raising low input DC voltage to greater levels when the load demands it [5]. However, it is frequently not possible to supply the entire power requirement with a single energy source. As a result, combining several energy sources into one power conversion stage has grown in popularity [6]. The Multi Input Boost Converter (MIBC) is ideal for hybrid renewable energy systems because it can combine numerous DC sources, such PV panels and batteries, into a single, higher, and steady DC output [7].

Despite these benefits, the fluctuating nature of each input source and changing load conditions make maintaining voltage stability in MIBC a significant issue [8]. An efficient control approach is necessary to guarantee stable functioning. One of the most popular control strategies in power electronics is the

proportional-integral (PI) controller because of its simplicity, convenience of use, and capacity to reduce steady-state error while delivering quick dynamic response. Through accurate duty cycle regulation of the MOSFET switches via Pulse Width regulation (PWM), the output voltage of the MIBC may be efficiently controlled by appropriately adjusting the PI settings [9].

The design, development, and experimental validation of a MIBC system with a PI algorithm control that is implemented on an Arduino Mega 2560 platform and programmed using MATLAB/Simulink are the main objectives of this study [10]. The study examines how well the suggested system performs in a range of operating conditions, such as step changes in reference setpoints, variations in input voltage, and changes in load resistance [11]. In order to improve the dependability and effectiveness of MIBC in renewable energy applications, the goal is to assess the PI controller's capacity to preserve output voltage stability, decrease transient overshoot, and lower steady-state error [12].

2. METHOD

Open-loop control systems operate without feedback, making output dependent solely on predefined settings and calibration, which can lead to performance degradation under disturbances. In contrast, closed-loop systems use feedback to compare output with a reference, process the resulting error, and adjust control actions to minimize deviations. Similar to a manual feedback process in humans—where the brain acts as controller, muscles as actuators, and eyes as sensors—closed-loop systems continuously monitor and correct output, ensuring stability and accuracy, unlike open-loop systems where output is not measured or fed back [13].

Figure 1. The Multi Input Boost Converter (MIBC) converts energy from two renewable sources, Vin1 and Vin2, using MOSFET switches controlled by a PI-based system with one voltage loop and two current loops. The voltage loop regulates output voltage (V_o), while the current loops control inductor currents (I_{L1} , I_{L2}) using real-time sensor feedback. V_o is compared to its reference to set a current reference (I_{ref}), which is matched against I_{L1} and I_{L2} ; the resulting errors generate PWM signals to drive the MOSFETs, controlling energy transfer to the load. Proper PI tuning ensures stable, efficient, and responsive operation under varying inputs and loads.

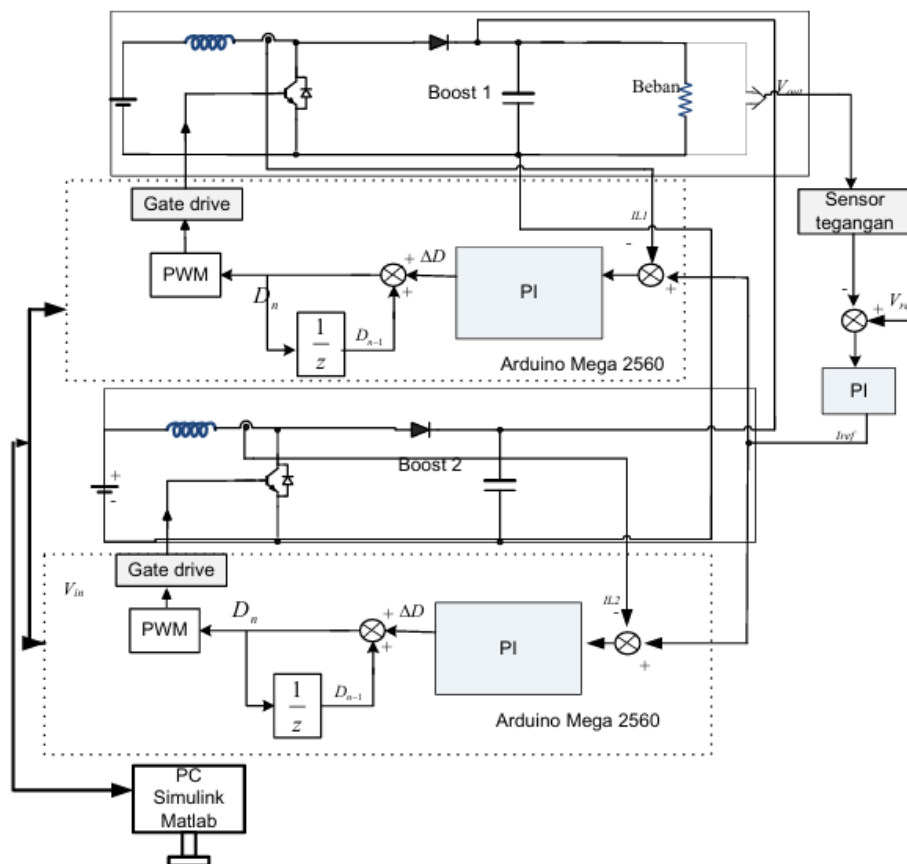


Figure 1. MIBC control scheme using PI

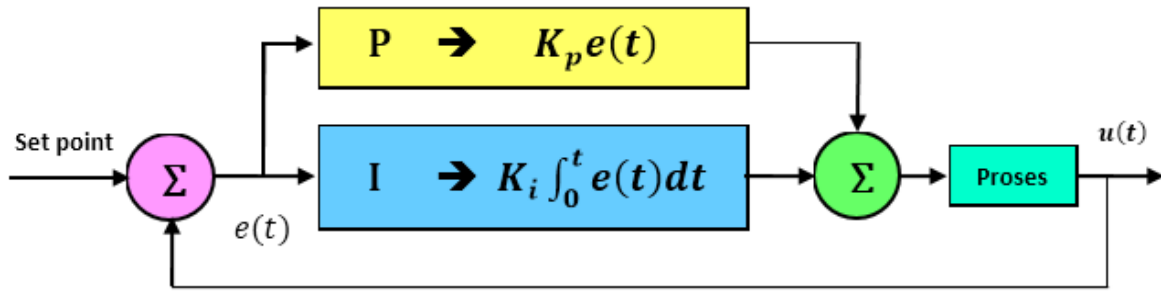


Figure 2. Proportional Integral (PI) system

A Proportional-Integral (PI) controller combines proportional (P) control, which amplifies the error to quickly approach the setpoint, and integral (I) control, which accelerates response and eliminates steady-state error. This combination improves rise time, reduces settling time, and enhances overall system performance [14].

The proportional (P) control method improves upon simple on/off control by providing continuous output adjustments based on the error magnitude [15]. Increasing the proportional gain (K) enhances responsiveness and reduces steady-state error, but excessive gain can cause oscillations and instability, creating a trade-off between speed and stability. While P control can improve rise time, settling time, and steady-state accuracy, it is often insufficient alone for optimal performance, as its effectiveness is limited by stability constraints.

The integral (I) controller eliminates steady-state error by integrating the accumulated error over time, producing an output proportional to the area under the error curve. While it ensures zero steady-state error in systems lacking an integrator, it responds more slowly than proportional control and may increase instability by raising system order. Tuning PI controllers can be done using methods such as Ziegler–Nichols, Cohen–Coon, or trial-and-error. In the trial-and-error approach, the I gain is initially set to zero while increasing the P gain for a fast yet stable response; the I gain is then gradually adjusted to reduce oscillations and remove steady-state error, with careful consideration to avoid overshoot.

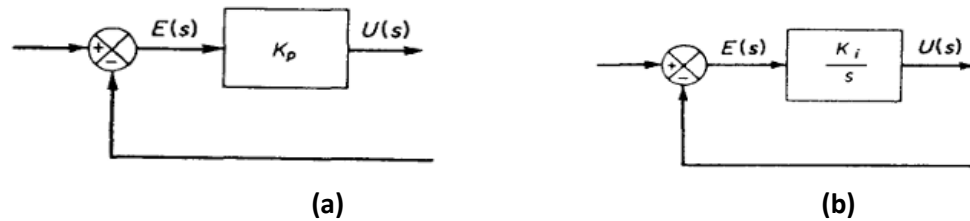
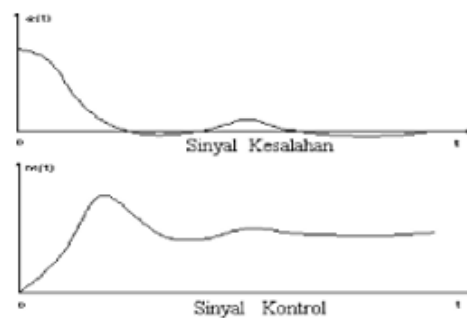


Figure 3. (a) Proportional Controller Block Diagram (b) Integral Controller Block Diagram

Figure 4. Error signal curve $e(t)$ versus t and output signal curve $u(t)$ versus t for zero-error generation.

PI parameter are written as :

$$u(t) = K_p e(t) + K_i \int_0^t e(t) dt \quad (1)$$

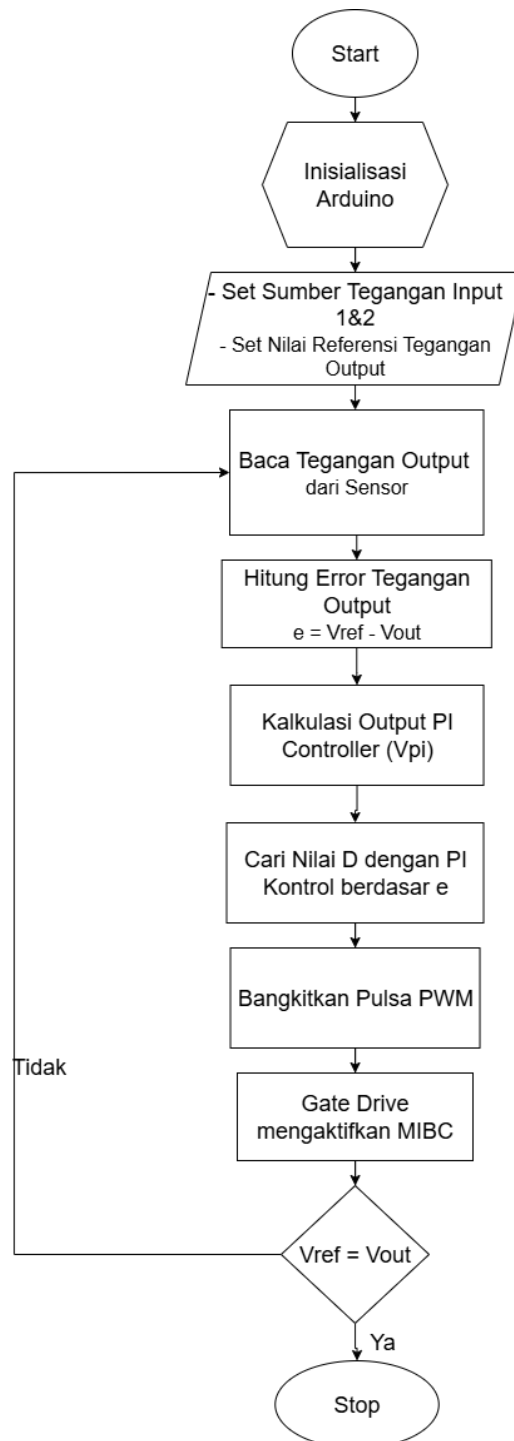


Figure 4. Overall System Flowchart

Figure 4. This flowchart illustrates the control process of a Multi Input Boost Converter (MIBC) using an Arduino-based Proportional-Integral (PI) controller. The operation begins with Arduino initialization to establish communication with sensors, the MOSFET driver, and the PWM module. Input sources V_{in1} and V_{in2} are set, and the reference output voltage (V_{ref}) is defined. The system measures the output voltage (V_{out}), calculates the error $e = V_{ref} - V_{out}$, and processes it through the PI controller to generate a control signal (V_{pi}). From this, the optimal duty cycle (D) is computed to drive the MOSFET via a PWM signal. The PWM is sent to the gate driver to activate the MIBC, adjusting the output voltage toward the target. This process repeats until V_{out} reaches or closely matches V_{ref} , ensuring stable output.

3. RESULTS AND DISCUSSION

After evaluating the device's effectiveness, the system is deemed to function as intended. This section presents the hardware and software testing results, starting with verifying each component's operation, followed by collecting data from predefined parameters and analyzing the outcomes.



(a)



(b)

Figure 5. DC Power Supply (a) DC power supply as input 1 (b) DC power supply as input 2

This project uses an ACS712 current sensor and a voltage divider circuit with two resistors as a voltage sensor. Both sensors were tested before system testing to ensure measurement accuracy. MATLAB Simulink was used to validate the readings, showing output currents of 0.21 A for Boost 1 and 0.12 A for Boost 2, with input voltage at 12 V and output voltage at 15.56 V—matching the instrument measurements. These results confirm the accuracy of the current and voltage sensors.



Figure 6. Hardware Boost Converter with Measuring Instrument

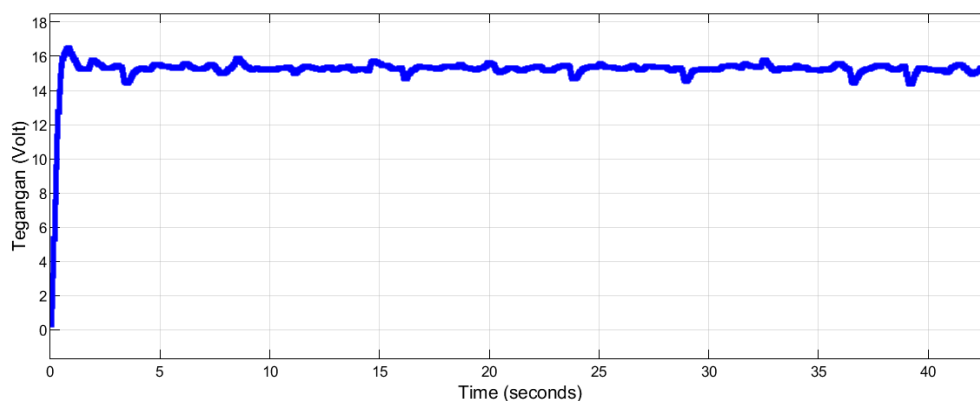


Figure 7. Output voltage sensor validation

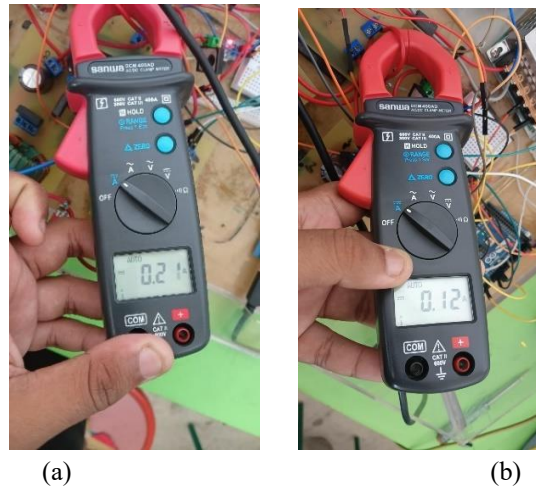


Figure 8. (a) Output current sensor validation of Boost 1 (b) Output current sensor validation of Boost 2

After validating the boost converter, the current sensor and voltage sensor were successfully implemented, then connected to a computer to run the program and load was applied.

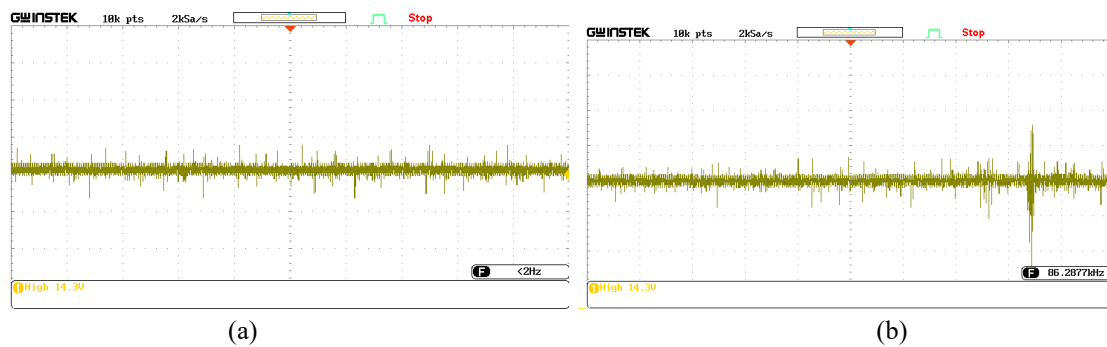


Figure 9. (a) Boost 1 Output Voltage (b) Boost 2 Output Voltage

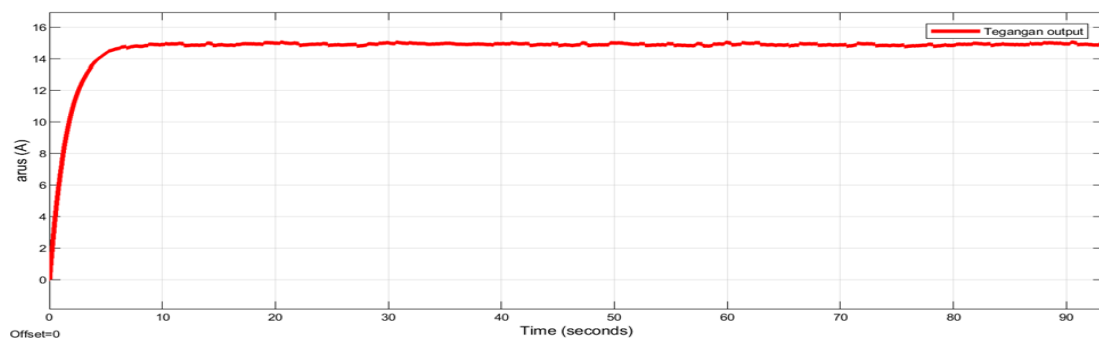


Figure 10. Overall Output Voltage

Figure 10. Two variable DC power supplies were used to test the boost converter without the MATLAB Simulink PI program. A constant duty cycle of 30% was applied to verify its operation based on the principle that the output voltage exceeds the input voltage. The test produced an output of 15 V, confirming that the boost converter functioned as intended.

Based on theory, the PI technique is designed to ensure that the controller maintains a stable output voltage at the reference value despite fluctuations in input voltage and load. The test results of the MIBC system with the PI algorithm are presented below, and the PI Simulink MATLAB program is shown in Figure 11.

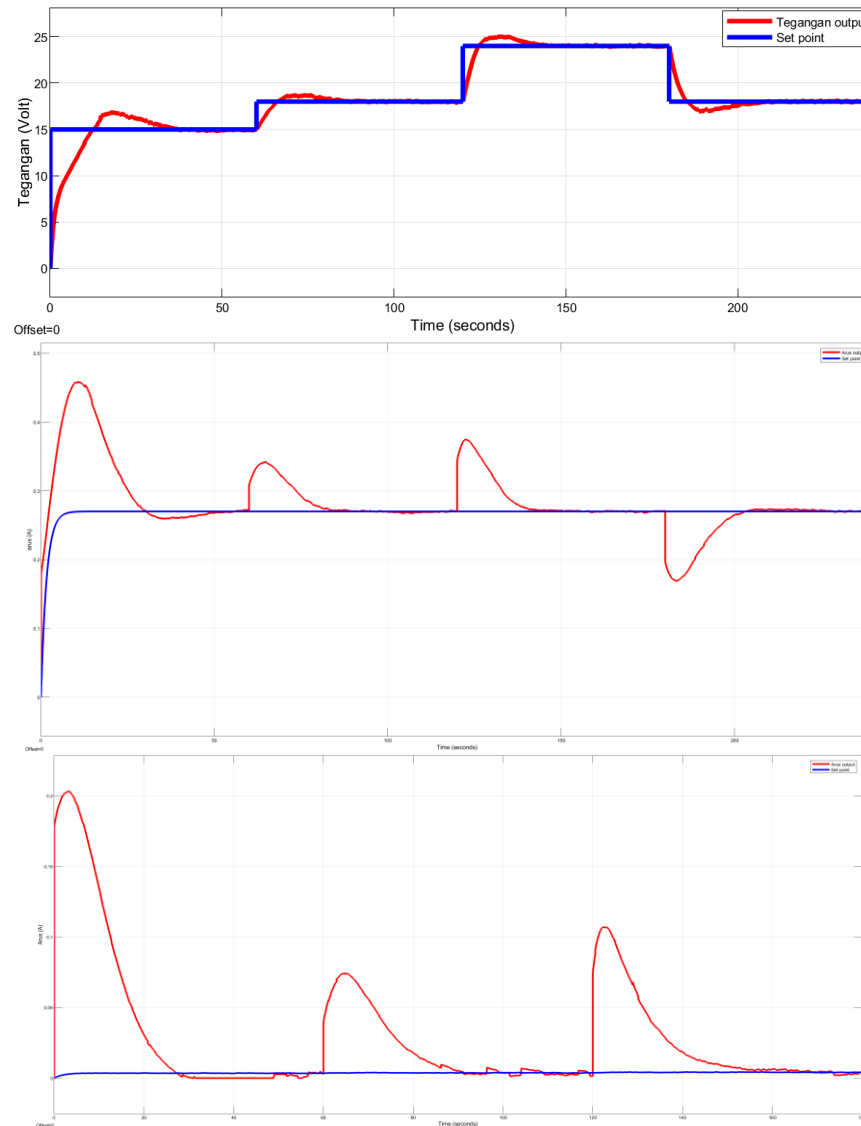


Figure 11. Output voltage, Boost 1 output current, and Boost 2 output current with varying setpoints

Figure 12 Uncontrolled operation of the multi-input boost converter in this test caused current surges and voltage drops. These high current spikes pose a risk of overheating the converter components. Therefore, a control system is necessary to ensure safe and proper operation of the boost converter.

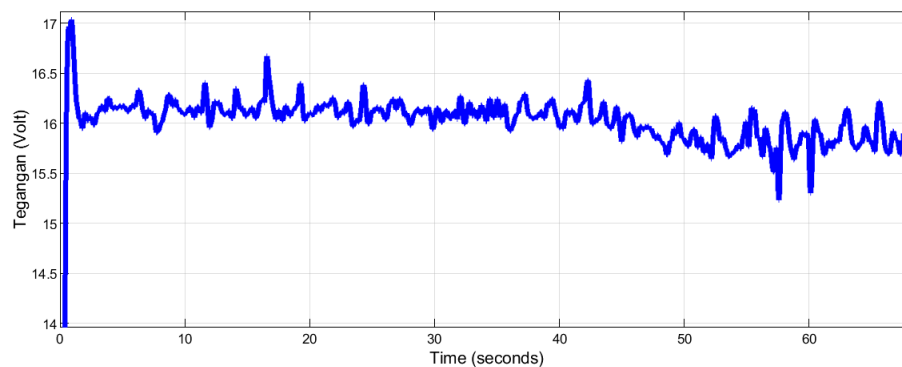


Figure 12. Uncontrolled output voltage with varying load.

4. CONCLUSION

In accordance with the planned specifications, the design and implementation of the Multi-Input Boost Converter (MIBC) with a PI controller have been successfully completed. Despite fluctuations in input voltage and load variations, the system maintained a stable output voltage at the reference value. Compared to the uncontrolled system, the Proportional-Integral (PI) controller quickly achieved stability, minimized overshoot, and reduced steady-state error. Test results demonstrated reliable operation, fast response time, and high efficiency. All research objectives were achieved, validating the implementation and evaluation of the PI-based MIBC as a reliable and effective power source.

REFERENCES

- [1] F. Mumtaz, N. Z. Yahaya, S. T. Meraj, R. Kannan, B. S. M. Singh and O. Ibrahim, "Multi-Input Multi-Output DC-DC Converter Network For Hybrid Renewable Energy Applications," *2020 International Conference on Innovation and Intelligence for Informatics, Computing and Technologies (3ICT)*, Sakheer, Bahrain, 2020, pp. 1-6, doi: 10.1109/3ICT51146.2020.9312026.
- [2] G. F. Laghari, A. Umar and S. Abdullah, "Comparative analysis of multi-input DC/DC converter topology for hybrid renewable energy systems," *2015 Power Generation System and Renewable Energy Technologies (PGSRET)*, Islamabad, Pakistan, 2015, pp. 1-5, doi: 10.1109/PGSRET.2015.7312254.
- [3] R. D. Saputra and M. Yuhendri, "Backpropagation neural network for DC-DC boost converter control using arduino microcontroller," *Journal of Industrial Automation and Electrical Engineering*, vol. 01, no. 01, pp. 111–117, 2024.
- [4] T. Mishra, "Synthesis and Modelling of A Novel Multi-Input Multi-Output System Topology Implemented on Non-Inverting Buck-Boost Converter for Renewable Energy Applications," *2022 First International Conference on Electrical, Electronics, Information and Communication Technologies (ICEEICT)*, Trichy, India, 2022, pp. 1-6, doi: 10.1109/ICEEICT53079.2022.9768503.
- [5] F. M. Iqbal, F. Agung Pamuji and H. Suryatomo, "Design Interleaved Multi Input DC-DC Boost Converter for Hybrid Wind-PV Renewable System," *2024 International Seminar on Intelligent Technology and Its Applications (ISITIA)*, Mataram, Indonesia, 2024, pp. 775–780, doi: 10.1109/ISITIA63062.2024.10667876.
- [6] R. Aravind, B. Chokkalingam, R. Verma, S. Aruchamy and L. Mihet-Popa, "Multi-Port Non-Isolated DC-DC Converters and Their Control Techniques for the Applications of Renewable Energy," in *IEEE Access*, vol. 12, pp. 88458–88491, 2024, doi: 10.1109/ACCESS.2024.3413354.
- [7] M. Z. Hossain, N. A. Rahim, and J. A. Selvaraj, "Recent progress and development on power DC–DC converter topology, control, design and applications: A review," *Renew. Sustain. Energy Rev.*, vol. 81, pp. 205–230, Jan. 2018, doi: 10.1016/j.rser.2017.07.017.
- [8] M. Yuhendri, E. Mirshad, and A. R. Sidiqi, "Real-time Control of Separately Excited DC Motor Based on Fuzzy PI System Using Arduino," *Przegląd Elektrotechniczny*, vol. 2024, no. 10, pp. 123–127, 2024, doi: 10.15199/48.2024.10.22.
- [9] Z. Rehman, I. Al-Bahadly, and S. Mukhopadhyay, "Multiinput DC–DC converters in renewable energy applications—An overview," *Renew. Sustain. Energy Rev.*, vol. 41, pp. 521–539, Jan. 2015, doi: 10.1016/j.rser.2014.08.033.
- [10] P. Gunawardena, N. Hou, D. Nayanisiri, and Y. Li, "A dual-input single-output DC–DC converter topology for renewable energy applications," *IEEE Trans. Ind. Appl.*, vol. 59, no. 2, pp. 1995–2006, Mar. 2023, doi: 10.1109/TIA.2022.3218619.
- [11] M. I. Esario and M. Yuhendri, "Kendali Kecepatan Motor DC Menggunakan DC Chopper Satu Kuadran Berbasis Kontroler PI.pdf," *JTEV (Jurnal Tek. Elektro dan Vokasional)*, vol. 6, no. 1, pp. 296–305, 2020.
- [12] S. Harini, N. Chellammal, B. Chokkalingam, and L. Mihet-Popa, "A novel high gain dual input single output Z-quasi resonant (ZQR) DC/DC converter for off-board EV charging," *IEEE Access*, vol. 10, pp. 83350–83367, 2022, doi: 10.1109/ACCESS.2022.3195936.
- [13] S. M. Hashemzadeh, V. Marzang, S. Pourjafar, and S. H. Hosseini, "An ultra high step-up dual-input single-output DC–DC converter based on coupled inductor," *IEEE Trans. Ind. Electron.*, vol. 69, no. 11, pp. 11023–11034, Nov. 2022.
- [14] F. Rahmadi and M. Yuhendri, "Kendali Kecepatan Motor DC Menggunakan Chopper DC Dua Kuadran Berbasis Kontroler PI," *JTEIN J. Tek. Elektro Indones.*, vol. 1, no. 2, p. 241, 2020, doi: https://doi.org/10.24036/jtein.v1i2.71.
- [15] S. Rostami, V. Abbasi, and N. Talebi, "Ultrahigh step-up multiport DC–DC converter with common grounded input ports and continuous input current," *IEEE Trans. Ind. Electron.*, vol. 69, no. 12, pp. 12859–12873, Dec. 2022, doi: 10.1109/TIE.2021.313185.