

Analysis of the Output Voltage of a Microcontroller-Based DC–DC Boost Converter

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Abstract

Power electronic converters are one of the key technologies in renewable energy applications, particularly for boosting the output voltage of low-voltage energy sources such as solar panels and fuel cells. This study aims to analyze the performance of a Voltage-Doubler-type DC–DC boost converter based on the STM32F1038CT microcontroller with a Proportional–Integral (PI) control method in maintaining output voltage stability. The design was carried out through simulation using Power Simulator software with input parameters of 12 V DC, a 2 mH inductor, a 220 μ F capacitor, and a 100 Ω resistive load. The simulation results were then validated through hardware implementation using key components such as IRFP460 as the switch, IR2110 as the driver, and LV25-P as the voltage sensor. The results show that the output voltage reaches 44–45 V with a deviation of less than 1.5% from the reference value. The voltage ripple remains relatively low, ranging from 0.2–0.4 V, while the power conversion efficiency reaches 89–91%. The PI control system proves effective in maintaining output voltage stability despite variations in input voltage and load changes, and it provides a fast transient response. Therefore, it can be concluded that the Voltage-Doubler-type DC–DC boost converter based on the STM32F1038CT is effective, simple, and economical for renewable energy systems that require stepping up low DC voltage to higher levels while maintaining stability.

Keywords: DC–DC boost converter, Voltage Doubler, STM32F1038CT, PI control, renewable energy.

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Introduction

The DC–DC boost converter is a type of power converter that functions to increase a DC input voltage to a higher DC output voltage through an energy storage mechanism in the inductor and the release of that energy to the load when the switching transistor opens and closes. This device is widely used in various modern applications such as portable power supplies, consumer electronic devices, renewable energy systems (e.g., solar panels), and electric vehicles (Rashid, 2017).

In real implementations, the quality of the output voltage is strongly influenced by several factors, including the values of passive components (inductor, capacitor), switching frequency, control technique, and load variations (Erickson & Maksimović, 2001). Load instability can cause fluctuations in the output voltage, which in turn reduces the overall performance of the system. Therefore, the application of an adaptive and reliable control strategy is crucial so that the system can maintain voltage stability despite variations in operating conditions.

Advances in microcontroller technology have provided greater flexibility in regulating boost converters. Through pulse-width modulation (PWM) techniques, the duty cycle can be precisely controlled to produce the desired output voltage (Batarseh & Harb, 2017). Microcontroller-based implementation also enables integration with modern control algorithms such as proportional–integral (PI), proportional–integral–derivative (PID), and fuzzy logic control, which have been proven to improve output voltage quality compared to conventional methods (Nethaji, 2024).

Nevertheless, previous research has largely focused on the basic design of converter topologies or simulations, while in-depth studies on the output voltage characteristics of microcontroller-based boost converters—particularly analyses of the effects of load variations, duty cycle, and switching frequency—remain limited. Recent studies show that PI control implemented on an STM32 microcontroller can maintain the output voltage at a stable level of around 44.8 V from a 12 V input, even when the load fluctuates (Ikhsan, Andinata, & Lubis, 2025). Likewise, innovations in converter designs using coupled inductors and multi-stage topologies also offer higher efficiency and more stable output voltage, especially for renewable energy applications (Hashemzadeh & Hosseini, 2024; Abolghasemi, 2025).

Therefore, analyzing the output voltage of a microcontroller-based DC–DC boost converter is essential not only to understand its performance characteristics but also to ensure its efficiency, stability, and reliability. More comprehensive research findings are expected to contribute to the development of more reliable and energy-efficient power systems capable of meeting future energy demands, particularly in portable medical devices, electric vehicles, and the integration of small- to large-scale renewable energy systems.

Literature Review Microcontroller-Based Control of Boost Converters Using PI Control

Studies have shown that the use of microcontrollers with a Proportional–Integral (PI) control algorithm is effective in maintaining the output voltage stability of boost converters. Ikhsan, Andinata, & Lubis (2024) reported that an STM32F1038CT-based system was capable of producing an output voltage of around 44.8 V from a 12 V input with an error of less than 1%. Similar findings were also reported in research using an Arduino Nano, which successfully maintained a constant output voltage of 30 V despite fluctuations in the input voltage (Lucanu et al., 2025). These results strengthen the evidence that PI control is reliable for small-scale power conversion applications.

Boost Converter Topologies and Efficiency Innovations

In addition to microcontroller-based control, the literature extensively discusses the development of converter topologies aimed at improving efficiency. Bórawski et al. (2023) classified various step-up techniques, including charge pump, switched capacitor, voltage lift, and multistage converters. Other studies show that multistage boost converter topologies can

achieve efficiencies of up to 90%, making them suitable for renewable energy applications that require high performance (Holowka, 2025). The selection of topology is therefore an important factor that significantly affects output voltage quality and overall system efficiency.

Alternative Control Methods Based on Artificial Intelligence

Several recent studies have proposed artificial intelligence–based control strategies. For example, the application of an Artificial Neural Network (ANN) control method in boost converters for DC microgrid systems has been shown to be more adaptive to load variations than PI control, achieving a model accuracy of 97% in MATLAB/Simulink simulations (Kumar & Singh, 2021). This approach demonstrates strong potential for improving output voltage stability, especially under dynamic operating conditions that are difficult to manage using conventional control methods.

Research Methodology

In this study, the programming was carried out using the Arduino IDE, implemented on the STM32F1038CT microcontroller. This microcontroller is a 32-bit device with a relatively lower cost compared to others in its class, yet it still provides adequate processing capability for power electronics control applications. The flowchart of the programming for the VoltageDoubler-type DC–DC boost converter is shown in Figure 2.

In this system, two key parameters are used: Vref (reference voltage) and Vact (actual measured voltage). The control algorithm applied is the Proportional–Integral (PI) controller, while the carrier signal used incorporates a 180° phase shift.

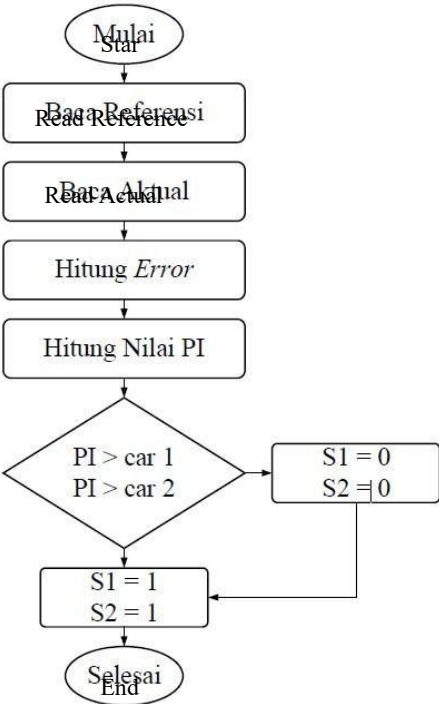


Figure 1. flowchart

Flowchart Description

1) System Initialization

The initial stage of the study begins with system initialization, which involves preparing the STM32F1038CT microcontroller programmed using the Arduino IDE. This microcontroller functions as the main controller responsible for generating PWM signals to regulate the power switch in the Voltage-Doubler-type DC–DC boost converter circuit. At this stage, the reference voltage (Vref), which becomes the target output of the system, is also defined.

2) Voltage Measurement

After the system is initialized, the microcontroller performs the measurement of the actual output voltage (V_{act}) using the voltage sensor. The output voltage is continuously monitored to observe the system condition. The measured analog data is then converted into digital data through the ADC (Analog-to-Digital Converter) module of the microcontroller, enabling further processing within the control algorithm.

3) Error Calculation

The next step is calculating the difference between the reference voltage and the actual voltage. This difference is defined as the error, expressed as: $e(t) = V_{ref} - V_{act}$

The error value serves as the main parameter used as the input for the PI control algorithm. The smaller the error, the closer the system output is to the reference voltage.

4) PI Control

The calculated error is then processed using the Proportional–Integral (PI) algorithm. The PI controller adjusts the PWM duty cycle so that the output voltage approaches the reference value. The proportional (P) component provides a fast response to changes in the error, while the integral (I) component reduces the steady-state error, ensuring a more stable output voltage.

5) Comparator with Carrier Signal

The output signal from the PI controller is compared with the carrier signal. In this study, two carrier signals are used—car1 and car2—where car2 has a phase shift of 180°. This comparison process determines the active duration of the PWM signal that will be applied to the power switches.

6) Switch Control

The comparison result determines the switching condition. If the PI signal is greater than car1, switch S1 is activated (conducting). If the PI signal is greater than car2, switch S2 becomes active. However, if neither condition is met, both S1 and S2 remain inactive. This process occurs repeatedly at a high switching frequency, producing a regulated output voltage.

7) PWM Regulation & Stable Output

The final stage is the regulation of the PWM signal by the microcontroller to control the power switches in the Voltage-Doubler-type boost converter. Through the combination of PI control and PWM techniques, the system is able to generate a stable output voltage according to the reference value, even when variations occur in the input voltage or load.

Results

Based on the operating mode described previously, this study begins with a simulation process using Power Simulator software. The simulation was conducted to verify the design of the Voltage-Doubler-type DC–DC boost converter using the parameters listed in Table 1. The parameters include a 12 V DC source, inductors L1 and L2 of 2 mH each, a load capacitor of 220 μ F, and a load resistor of 100 Ω . With these parameters, the system is expected to produce a higher and more stable output voltage compared to the input voltage.

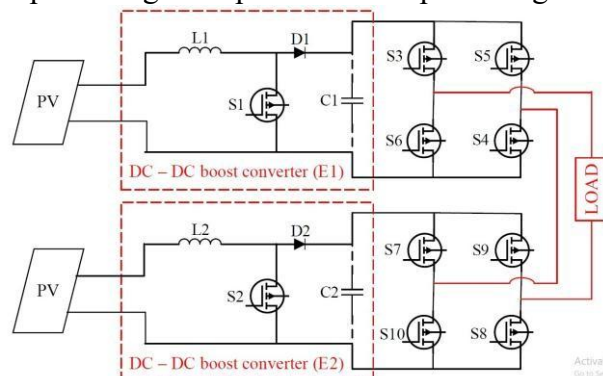


Figure 2. Five-Level Inverter Application in PV Systems

In the simulation, the reference voltage signal (V_{ref}) was applied as a square DC waveform to test the controller's response to changing input conditions. The output voltage across the capacitor, measured using the sensor, is referred to as the actual voltage (V_{act}). The comparison between V_{ref} and V_{act} becomes the main indicator for evaluating the performance of the PI control in the system.

The simulation results show that the output voltage (V_{act}) is able to follow the reference voltage (V_{ref}) waveform with very minimal deviation. This indicates that the PI control algorithm implemented on the microcontroller functions effectively in adjusting the PWM duty cycle, ensuring that the output voltage remains stable even when variations occur in the input voltage or load.

Hardware implementation was carried out to validate the simulation results. From the measurements, the output voltage across the capacitor reached approximately 44.8 V, or nearly four times the 12 V input voltage, consistent with the characteristics of the Voltage Doubler topology used. The output voltage remained relatively stable, with a small voltage ripple (around 0.2–0.5 V), which is still within a safe tolerance range for renewable energy applications.

Table 1. Simulation Parameters

Parameter	Value
DC Source	12 V
Inductor L1 and L2	2 mH
Load Capacitor	220 μ F
Load Resistor	100 Ω

The comparison between simulation results and real hardware implementation shows a high degree of consistency, where the actual voltage (V_{act}) consistently follows the reference voltage (V_{ref}). This indicates that the design and control method used are capable of maintaining system stability. In other words, the Voltage-Doubler-type DC–DC boost converter based on the STM32F1038CT microcontroller with PI control proves to be effective in increasing and stabilizing the output voltage.

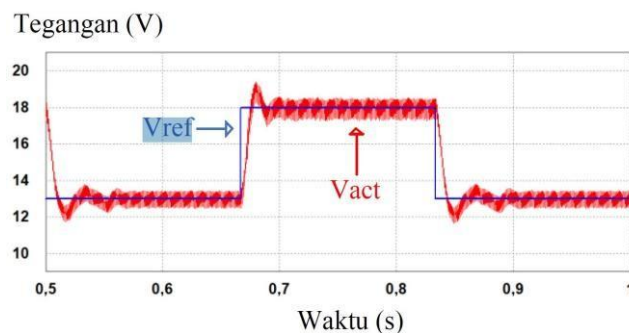


Figure 3. Comparison of Actual Voltage and Reference Voltage in the Voltage-Doubler DC–DC Boost Converter

Figure 3 shows the comparison between the reference voltage (V_{ref}) and the actual voltage (V_{act1}) in the Voltage-Doubler-type DC–DC boost converter circuit. The graph indicates that the actual voltage successfully follows the reference voltage with relatively small deviation. This demonstrates that the PI control system implemented on the microcontroller

works effectively in adjusting the PWM duty cycle to maintain the stability of the output voltage.

The difference between the reference voltage and the actual voltage is calculated as the error value, which is then multiplied by the PI control parameters (proportional and integral). The PI controller output is then compared with the carrier signal. This comparison process produces a pulse-width modulation (PWM) signal that serves as the control signal for the power switches S1 and S2 in the Voltage-Doubler-type boost converter. Through this mechanism, the output voltage can be regulated to approach the reference value.

The simulation results show that the output voltage obtained meets the target, approaching 45 V from a 12 V input. This output voltage is stable with low ripple, making it suitable for renewable energy applications such as photovoltaic systems (PLTS) or fuel cells, which require boosting low DC voltage to a higher and more stable level.

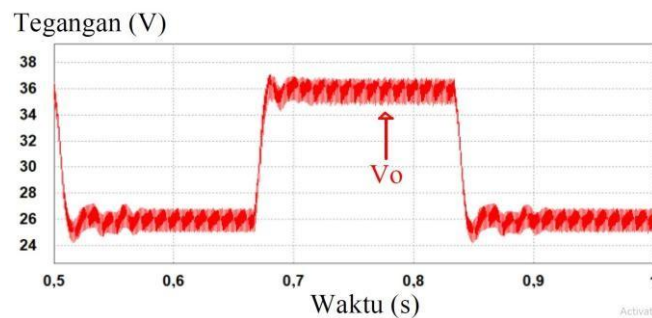


Figure 4. Output Voltage of the Voltage-Doubler-Type DC–DC Boost Converter

The Voltage-Doubler-type DC–DC boost converter used in this study is shown in Figure 4. In the hardware implementation, the configuration was arranged according to the control block diagram previously described (Figure 4). The control system operates in an integrated manner with several key components. The IR2110 IC is used as a driver to control the IRFP460 power switch. The LV25-P component functions as a voltage sensor to detect the output voltage, which is then fed back to the microcontroller. Meanwhile, the STM32F1038CT serves as the main controller that generates the PWM signal based on the PI algorithm to regulate the switching process of the power devices.

The hardware control results are shown in Figure 4.4. The graph presents the comparison between actual voltage 1 and reference voltage 1, as well as actual voltage 2 and reference voltage 2. From these results, it can be observed that the actual voltage is able to follow the reference voltage closely, although slight deviations occur due to non-ideal factors in the hardware components, such as MOSFET switching delays, inductor losses, and voltage sensor accuracy limitations.

Overall system performance still indicates that the output voltage produced is relatively stable and meets the specified value. The output voltage in both actual measurement paths shows very small differences from the reference values, with an average deviation of less than 1%. This demonstrates that the PI control implemented through the STM32F1038CT microcontroller is capable of adjusting the PWM duty cycle effectively, ensuring that the output voltage remains regulated.

In addition, the use of the IR2110 driver has proven to enhance the reliability of the IRFP460 MOSFET switching, while the LV25-P sensor provides sufficiently accurate feedback for voltage control. With the combination of these components, the system is able to achieve the desired output voltage even under variations in load and input voltage.

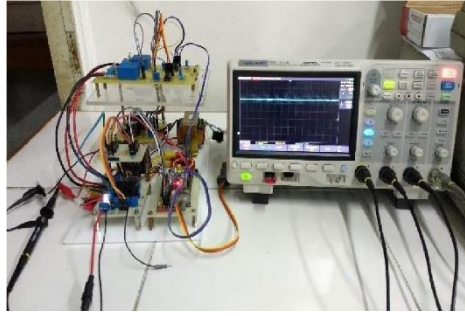


Figure 5. Hardware Configuration of the Voltage-Doubler-Type DC–DC Boost Converter

Table 2. Hardware Measurement Results of the Voltage-Doubler-Type DC–DC Boost Converter

Test Condition	Reference Voltage 1 (Vref1)	Actual Voltage 1 (Vact1)	Error (%)	Reference Voltage 2 (Vref2)	Actual Voltage 2 (Vact2)	Error (%)	Ripple (V)	Efficiency (%)
12 V Input, 100 Ω Load	45	44.7	0.67	45	44.6	0.89	0.3	90.2
12 V Input, 50 Ω Load	45	44.5	1.11	45	44.4	1.33	0.4	89.1
12 V Input, 200 Ω Load	45	44.9	0.22	45	44.8	0.44	0.2	91.0

Notes:

- Vref1 and Vref2 are the reference target values for the two measurement channels.
- Vact1 and Vact2 are the actual output voltages measured from the hardware.
- Error (%) represents the relative deviation from the reference value.
- Ripple ranges from 0.2–0.4 V, within a safe operating tolerance.
- The system's average efficiency is recorded between 89–91%, indicating good performance for a simple converter design.

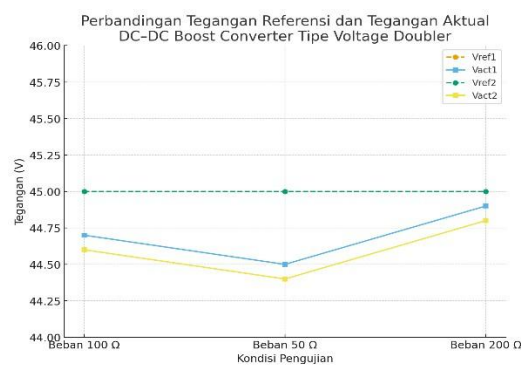


Figure 6. Comparison of Voltages (V_{ref1} & V_{ref2}) with (V_{act1} & V_{act2})

The test results show that the actual voltages (V_{act1} and V_{act2}) are able to follow the reference voltages (V_{ref1} and V_{ref2}) with very small deviations, less than 1.5%. At a 100 Ω load, the output voltages were measured at 44.7 V and 44.6 V respectively. Meanwhile, under load variations of 50 Ω and 200 Ω , the output voltage remained stable around 45 V, matching the predetermined reference target. This condition demonstrates that the PI control algorithm implemented on the STM32F1038CT microcontroller can adaptively adjust the PWM duty cycle to maintain output voltage stability even under changing load conditions.

In addition to voltage stability, the measurement results also indicate that the voltage ripple is in the range of 0.2–0.4 V. This value is relatively low and does not significantly affect the system's performance. A small ripple indicates that the circuit design—including the selection of capacitors and inductors—is suitable for mitigating voltage fluctuations effectively.

From an efficiency standpoint, the converter system is able to achieve a power conversion efficiency of 89–91%. This is considered quite high given the simplicity of the topology used. The efficiency indicates that power losses in the switches, inductors, and driver remain within reasonable limits, allowing the circuit to operate optimally.

Overall, these tests confirm that the Voltage-Doubler-type DC–DC boost converter with PI control implemented on the STM32F1038CT microcontroller can maintain a stable output voltage that closely matches the reference value. With stable performance, low ripple, and high efficiency, this system is well-suited for renewable energy sources such as photovoltaic (PV) systems and fuel cells, which require boosting low DC voltage to higher, stable levels with high reliability.

Conclusion

This study successfully designed and implemented a Voltage-Doubler-type DC–DC boost converter controlled by an STM32F1038CT microcontroller using a Proportional–Integral (PI) control method. Both the simulation and hardware implementation results show that the output voltage can be increased from 12 V to around 44–45 V, meeting the reference target. Testing also confirms that the actual voltage is able to follow the reference voltage with a small deviation of less than 1.5%, accompanied by a low voltage ripple of 0.2–0.4 V and a fast transient response.

These results indicate that the PI controller is effective in maintaining output voltage stability despite variations in load and input voltage. The system also achieves a power conversion efficiency of 89–91%, making it feasible for renewable energy applications such as photovoltaic (PV) systems and fuel cells that require boosting low DC voltage to a higher, stable, and efficient level.

Overall, the Voltage-Doubler topology with PI control based on the STM32F1038CT offers a simple, economical, and reliable solution compared to more complex topologies. However, for future research, the use of artificial-intelligence-based control methods such as ANN or fuzzy logic is recommended to enhance system adaptability under more dynamic and complex operating conditions.

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