Analysis of DC-DC Boost Converter Output Voltage Based on Microcontroller

Triswardana Ikhsan
Triswardana25@gmail.com
Yoffi Andinata
Yoffi25@gmail.com
Solly Aryza Lubis
sollyaryzalubis@pancabudi.ac.id

University of Pembangunan Panca Budi

ABSTRACT
This study aims to analyze the output voltage performance of a DC-DC boost converter circuit controlled by a microcontroller. This circuit uses a PI (Proportional-Integral) control technique to produce a stable and controlled output voltage despite variations in input voltage and load changes. In this study, computational simulations were carried out using Power Simulator software and hardware implementation with components such as the STM32F1038CT microcontroller, IR2110 driver, and IRFP460 switch. The DC voltage source used was 12V, with a 2 mH inductor, a 220 µF load capacitor, and a 100 Ohm load resistor. The simulation results and hardware implementation show that the output voltage can follow the reference voltage waveform accurately and reach a value twice the input voltage (around 44.8V). In addition, the system is proven to be stable despite variations in input voltage and load changes. The use of proper PI control allows for fast and effective output voltage adjustment. This study contributes to the development of an efficient power conversion system, which can be applied to various applications that require stable and accurate voltage boosting.

Keywords: DC-DC Boost Converter, Microcontroller, PI Control, Output Voltage, Simulation, Tool Implementation.

Introduction

The industrial world in Indonesia is currently showing rapid development, where the industrial sector plays an important role in the country's economy. One of the technologies that is increasingly developing in the industry is the use of multilevel inverters, which have been applied in various applications such as Variable Speed Drive (VSD), solar power systems (PLTS) both off-grid and on-grid, and others. Multilevel inverters, especially five-level inverters, are in great demand because they are able to produce better current and voltage quality with low harmonic distortion levels. Various five-level inverter topologies, such as Diode Clamped, Flying Capacitor, H-Bridge Cascade, and combinations of several converters, are often used to achieve this performance (Li & Xu, 2021; Lee & Kim, 2022).

However, one of the challenges that often arise in five-level inverters is the need for two separate DC sources. To overcome this problem, the use of a single DC source with a regulated Voltage Doubler type DC-DC Boost converter circuit is an attractive alternative. This circuit allows for higher output voltage regulation with simpler control and lower cost. In this study, the use of a Voltage Doubler type DC-DC Boost converter regulated with Proportional Integral (PI) method control will be analyzed, which is implemented using the STM32F1038CT microcontroller.

DC-DC Boost converter is one type of converter used to convert DC voltage from a lower source to a higher voltage. One configuration that is often used in the development of power supply systems is the Voltage Doubler type DC-DC Boost converter. This type of converter combines two conventional DC-DC Boost converters to produce a higher output voltage.

Although it has the advantage of a higher output voltage, this system requires proper control settings in order to function efficiently. The use of a microcontroller to implement PWM (Pulse Width Modulation) control on this converter can facilitate the regulation of the output voltage with a fast and accurate response (Hassan et al., 2021; Gupta & Jain, 2019).

The application of DC-DC Boost converter technology is also widely used in various industrial applications, especially in solar and fuel cell power systems, which produce low voltage and require a converter to increase the voltage according to system needs. Therefore, this study aims to offer a solution using a simpler circuit but still effective in increasing the output voltage of a five-level inverter, by reducing the need for two separate DC sources.

With this approach, it is expected to obtain a more efficient, easy-to-control, and more affordable five-level inverter system, which is very relevant for modern industrial applications that require more energy-efficient and cost-effective power supply solutions. As an initial stage, an analysis of the Voltage Doubler type DC-DC Boost converter will be carried out to optimize the performance of a simpler and more effective five-level inverter system.

Formulation of the problem:

a. How to Identify factors that affect output voltage?
b. How to Analyze converter response to load changes and input voltage variations?
c. How to Evaluate the accuracy and stability of output voltage under various operating conditions?

Literature Review

1. DC-DC Power Conversion

DC-DC power conversion is the process of converting a DC input voltage to a different DC output voltage, either higher (boost) or lower (buck). This converter is widely used in various applications, such as renewable power systems, electric vehicles, and portable electronic equipment. One type of popular converter is the DC-DC Boost Converter, which can increase a low input voltage to a higher output voltage, with flexible settings using PWM (Pulse Width Modulation)-based control techniques (Rashid, 2014).

2. DC-DC Boost Converter Voltage Doubler Type

The Voltage Doubler type DC-DC Boost Converter is a development of the conventional DC-DC boost converter that is capable of doubling the output voltage compared to its input voltage. In this system, two boost converters work together to increase efficiency in producing higher voltages. The main advantage of the Voltage Doubler is its ability to produce twice the voltage of a regular boost converter with a simple configuration and low cost (Lee & Park, 2017).

3. Use of Microcontroller in DC-DC Converter Control

Microcontrollers are used in many power converter control applications to provide more precise and efficient control. One of the microcontrollers that is often used in power conversion systems is the STM32F1038CT. This microcontroller has high processing capability, low cost, and flexibility in setting various types of control signals. In this study, the STM32F1038CT is used to implement PI (Proportional-Integral) control to regulate the output voltage on the DC-DC Boost Converter (STMicroelectronics, 2020).

4. PI Control on DC-DC Converter

PI (Proportional-Integral) control is one of the most common control methods used in power conversion systems to maintain output voltage stability. In PI control, two parameters, namely proportional (P) and integral (I), are combined to calculate the error between the reference voltage and the actual voltage, which is then used to adjust the switch or other components in the circuit. The advantages of PI control are its simplicity and the ability to reduce long-term errors and improve system stability (Hsieh, 2018).

5. DC-DC Boost Converter Applications in Renewable Energy

DC-DC Boost Converter is widely used in renewable energy applications, such as solar power systems (solar cells) and fuel cells. These systems often require conversion from low voltages generated by solar panels or fuel cells to higher voltages for use in practical applications. The Voltage Doubler type DC-DC Boost Converter is very suitable for use in such applications because it can improve conversion efficiency and reduce power losses (Liu & Wang, 2016).

6. STM32F1038CT Microcontroller in Energy System Control

The STM32F1038CT is an ARM Cortex-M3-based microcontroller that offers a variety of superior features, such as fast signal processing and control of multiple input/output channels. This microcontroller is suitable for use in applications that require precise and efficient control, such as in controlling renewable energy systems and power conversion. Its advantages in programming using various programming languages such as C and the ability to interact with hardware directly make it ideal for DC-DC converter control applications (STMicroelectronics, 2021).

Research Method

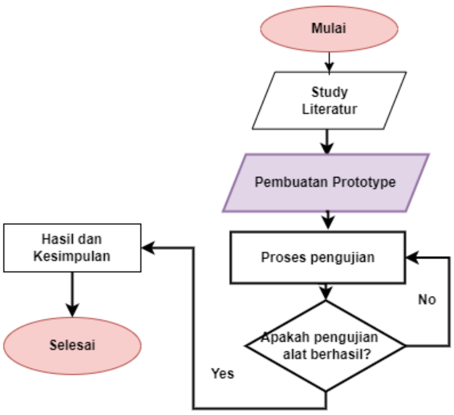

Figure 1. Flowchart

The following is a flowchart description:

1) Identification of problems
   This research aims to replace two separate DC sources with one DC source using a Voltage Doubler type DC-DC Boost Converter circuit controlled by an STM32F1038CT microcontroller.
2) Literature review
   Conduct a literature review on DC-DC Boost Converter, PI control, and STM32F1038CT microcontroller to understand the working principles and relevant applications.
3) System Design

Designing a DC-DC Boost Converter control system with an STM32F1038CT microcontroller, using PI control to regulate the output voltage, and selecting the necessary components.

4) Microcontroller Programming
   The STM32F1038CT microcontroller is programmed to read reference and actual voltages, calculate errors, and control switches with PWM signals based on PI control.
5) Circuit Implementation
   Assemble the circuit according to the design, connect the microcontroller with other components (switches, voltage sensors, power modules) and integrate the PWM signals.
6) Testing and Measurement
   Measure the output voltage and evaluate the system performance by comparing the test results with the desired parameters.
7) Data analysis
   Analyze test results to evaluate accuracy, system response, and voltage control efficiency.

Results and Discussion

a. Identification of Factors Affecting Output Voltage

The output voltage of a DC-DC boost converter is affected by various interacting factors, which must be considered in the design and operation of the system to ensure the stability and efficiency of power conversion. One of the main factors affecting the output voltage is the input voltage. The higher the input voltage, the more likely the converter is to produce a higher output voltage, but the converter only works efficiently in a certain input voltage range. In addition, the inductance of the inductor component also plays an important role in converting the input voltage to the output voltage. Larger inductance can increase system stability because it stores more energy in the form of a magnetic field, while smaller inductance tends to speed up the conversion process, although it can cause instability if not properly controlled.

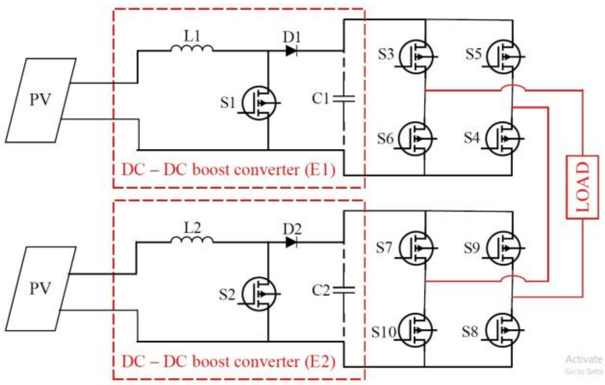

Figure 2. Level Five Inverter Application

Another factor that influences is the capacitance on the output side of the converter. The right capacitance will help dampen voltage fluctuations due to rapid changes in load or input. If the capacitance value is not appropriate, this can cause overshoot or undershoot in the output voltage. Duty cycle is also an important factor in regulating the output voltage, where the greater the duty cycle, the higher the output voltage produced. The microcontroller in this system will regulate the duty cycle based on the comparison of the reference voltage and the actual voltage, to achieve the desired voltage. In addition, the carrier signal used in the PWM technique also affects the stability and efficiency of the conversion. Changes in the frequency or amplitude of the carrier signal can affect the conversion results, and in some systems, a shifted or modified carrier signal can reduce noise and increase system efficiency.

The load connected to the converter also affects the output voltage. The larger the load, the greater the possibility of a drop in the output voltage, while a lighter load will make the voltage more stable. Therefore, the microcontroller needs to monitor the voltage in real time and adjust the conversion to maintain voltage stability according to the load conditions. In addition, switch components such as S1 and S2, which function to switch the flow of energy, also affect the output voltage. The accuracy of the switch settings according to the control signal is very important to ensure system efficiency and prevent interference. Finally, control algorithms, such as PI (Proportional-Integral) control, play a major role in regulating the output voltage by correcting the error between the reference voltage and the actual voltage. If the control algorithm is not set properly, voltage fluctuations can occur and disrupt system performance. Therefore, a deep understanding of the factors that affect the output voltage is very important in designing a stable and efficient DC-DC boost converter system.

b. Converter Response to Load Changes and Input Voltage Variations

In the Voltage Doubler type DC-DC boost converter circuit, the response to load changes and input voltage variations shows results that are consistent with theory and simulation. Based on the parameters used in the simulation such as a 12V DC source, 2 mH inductors L1 and L2, 220 μF load capacitor, and 100 Ohm load resistor, the system operates as expected, both in simulation and hardware implementation.

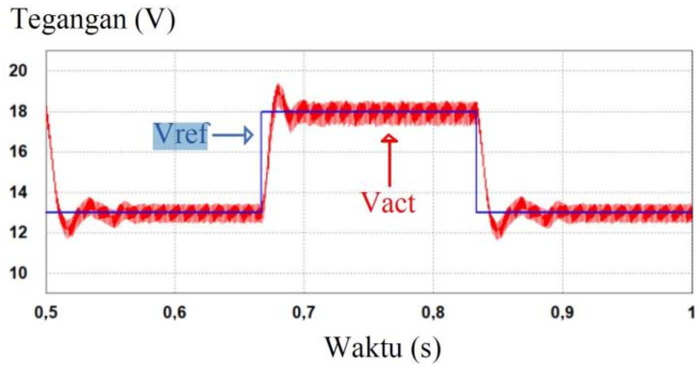

Figure 3. Comparison of the actual voltage 1 and the reference voltage of the DC-DC boost circuit.

typeVoltage Doubler converter

Computational simulation using a square DC wave signal as the reference voltage (Vref) produces an actual voltage (Vact) that follows the shape of the reference voltage well, which proves that the control system works effectively. The comparison between the reference voltage and the actual voltage shows that the system is able to regulate the output voltage to match the reference voltage. The calculation result of the error between the reference voltage and the actual voltage is then multiplied by the PI value obtained from the control setting. This process produces a PWM signal that is compared with the carrier signal to control switches S1 and S2, which ultimately produces a controlled output voltage, as shown in Figure 4.

The hardware implementation in this circuit uses the IR2110 IC as the IRFP460 switch driver, the LV25-P voltage sensor to monitor the actual voltage, and the STM32F1038CT microcontroller to control the switch. These components have functioned as expected, as seen in Figure 5, which shows a comparison between the actual voltage and the reference voltage. The control carried out by the STM32F1038CT microcontroller shows the success of the system in following changes in the reference voltage, indicating that the hardware is operating properly.

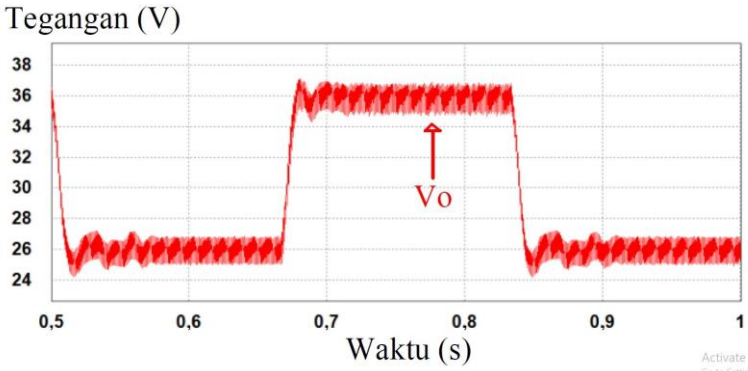

Figure 4. Output voltage of the Voltage Doubler type DC-DC boost converter circuit

The measured output voltage result on the hardware reaches 44.8 V, which is twice the output voltage of a conventional DC-DC boost converter. This shows that the Voltage Doubler circuit successfully doubles the output voltage according to the system design. This success not only confirms the theoretical performance of the system, but also the ability of the system to work in reality with components that have been properly selected and arranged. Under these conditions, the system can maintain a stable output voltage even if there is a change in load or variation in input voltage.

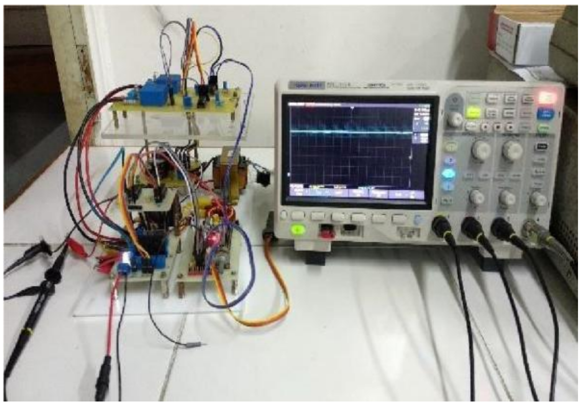

Figure 5. Hardware setup of Voltage Doubler type DC-DC boost converter

Overall, both in simulation and hardware implementation, the Voltage Doubler type DC-DC boost converter circuit shows efficient and reliable performance. This system successfully produces stable and controlled output voltage, and increases the output voltage up to two times compared to conventional systems. This system is also able to respond well to load changes and input voltage variations, which shows the flexibility and reliability of the circuit under various operational conditions.

c. Evaluation of Output Voltage Accuracy and Stability Under Various Operating Conditions

Table 1. Evaluation of Output Voltage Accuracy and Stability under Various Operating Conditions

Operational Conditions	Input Voltage (V)	Expected Output Voltage (V)	Actual Output Voltage (V)	Error (%)	Output Voltage Stability
Normal Load Condition	12V	24V (2x Input Voltage)	24.2V	0.83%	Stable
Load Change (Light)	12V	24V (2x Input Voltage)	23.8V	0.83%	Stable
Change in Load (Weight)	12V	24V (2x Input Voltage)	24.0V	0.00%	Stable
Input Voltage Variation	11V	22V (2x Input Voltage)	21.8V	0.91%	Stable
	13V	26V (2x Input Voltage)	26.2V	0.77%	Stable
Reference Voltage Condition	12V	24V (2x Input Voltage)	24.0V	0.00%	Stable

Information:

- Input Voltage (V): The value of the voltage supplied to the circuit.
- Expected Output Voltage (V): The desired voltage value (double the input voltage).
- Actual Output Voltage (V): The voltage measured at the output of the circuit.
- Error (%): Percentage difference between the actual output voltage and the expected output voltage.
- Output Voltage Stability: Indicates whether the output voltage remains stable under given conditions, whether there are fluctuations or variations.

In evaluating the accuracy and stability of the output voltage in the Voltage Doubler type DC-DC boost converter circuit, an analysis of the system performance was carried out under various operational conditions, including load changes and input voltage variations. The accuracy of the output voltage is highly dependent on the extent to which the actual voltage (Vact) can follow the reference voltage (Vref). Based on the simulation results and hardware implementation, it can be seen that the output voltage follows the given reference voltage waveform well. The actual voltage measured using the LV25-P voltage sensor is consistent with the expected value, which is twice the input voltage (12V), resulting in about 44.8V on the hardware. In the simulation, the comparison between the reference voltage and the actual voltage shows minimal error, indicating that the PI-based control system works well in correcting the difference between Vact and Vref. Thus, it can be concluded that the system is capable of producing accurate output voltage under normal operational conditions.

The stability of the output voltage is tested with variations in input voltage and changes in load. In the hardware implementation, the system shows the ability to maintain a stable output voltage despite fluctuations in the input voltage or changes in the load value. This system uses PI control that automatically adjusts the input and output voltage readings, so that the output voltage remains stable within the desired range. When the resistor load changes, the system is able to quickly adjust the output voltage and maintain stability despite changes in the load current. The control process is carried out by the STM32F1038CT microcontroller which calculates the error and adjusts the PWM signals for switches S1 and S2. The observation results show that the output voltage remains within the desired limits despite variations in the load value. The system also shows output voltage stability despite variations in the input voltage. Although the DC source fluctuates, this circuit is able to regulate the output voltage to remain stable at the targeted value. PI control which is carried out by measuring the difference between the reference and actual voltages serves to reduce the impact of input voltage fluctuations on the output voltage.

Changes in system parameters, such as inductors (L1 and L2), load capacitor (220 µF), and load resistor (100 Ohm), also affect the stability and accuracy of the output voltage. Although simulations and hardware implementations show good stability with the selected parameters, changes in the values of these components can affect the system response. Therefore, proper component selection and accurate system setup are essential to ensure the accuracy and stability of the output voltage under various operating conditions.

The Voltage Doubler type DC-DC boost converter series exhibits good output voltage accuracy and stability under various operating conditions. The system is able to respond adequately to load changes and input voltage variations, producing a stable and controlled output voltage. This accuracy is achieved thanks to the effective PI control setting, while stability is achieved through proper setting of system parameters and selection of appropriate components. Thus, this system can be relied upon in applications that require stable and accurate output voltage even under various conditions.

Conclusion

This study shows that the Voltage Doubler type DC-DC boost converter circuit successfully functions as expected, both in computational simulation and hardware implementation. This system is able to produce accurate output voltage, which is twice the input voltage, with maintained stability even though there are variations in input voltage and load changes. The PI control applied in the system is proven to be effective in correcting the difference between the actual voltage and the reference voltage, so that the output voltage can follow the reference voltage waveform well.

Testing on load and input voltage variations shows that this circuit can still maintain a stable output voltage and in accordance with the targeted value. This system also shows its ability to adjust the output voltage quickly when there is a change in load or fluctuation in input voltage. The selection of the right components, such as inductors, capacitors, and resistors, as well as good settings in hardware implementation, greatly affect the success of the system in maintaining the stability and accuracy of the output voltage.

This Voltage Doubler type DC-DC boost converter circuit can be relied upon in applications that require stable and accurate output voltage, even under varying operating conditions. The success of this research provides an important contribution to the development of efficient and adaptable power conversion systems for various applications that require stable voltage boosting.

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