Transformerless DC-DC Converters with High Step-Up Voltage Gain

A PROJECT REPORT

submitted in partial fulfillment of the course

Switched Mode Power Conversion

By

Yamini Kumari 20BEE1032

Sabareesh M 20BEE134

Udhaya Shankar P 20BEE1028

under the guidance of

Dr. Jayapragash R

SCHOOL OF ELECTRICAL ENGINEERING

VIT CHENNAI

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CERTIFICATE

This is to certify that the project work titled **“Transformerless DC-DC converter with High Step-up Voltage Gain”** submitted by **Yamini kumari 20BEE1032, Sabareesh M 20BEE1034, Udhaya Shankar P 20BEE1028**is in partial fulfillment of the requirements for the award of the degree of **BACHELOR OF TECHNOLOGY**, is a record of bona fide work done under my guidance. The contents of this project work, in full or in parts, have neither been taken from any other source nor have been submitted to any other Institute or University for award of any degree or diploma and the same is certified.

Project Supervisor

Approved by

Head of the Department

B.Tech Electrical and Electronics Engineering

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Yamini kumari 20BEE1032

Sabareesh M 20BEE1034

Udhaya Shankar P 20BEE1028

ABSTRACT

This paper addresses the limitations of conventional DC-DC boost converters in achieving high step-up voltage gains and introduces a transformerless approach to overcome these challenges. By strategically employing two inductors with equal inductance in parallel during switch-on and in series during switch-off, the proposed converters achieve significant voltage boosts without requiring an excessively high duty ratio. The simplicity of the converter structure, utilizing only one power stage, distinguishes this approach. The paper provides detailed steady-state analyses of voltage gains and boundary operating conditions, enhancing understanding and facilitating practical implementation. A prototype circuit is implemented in the laboratory, confirming the effectiveness of the proposed transformerless DC-DC converters. The inherent limitations of conventional DC-DC boost converters, stemming from factors like power switch characteristics and component resistances, often hinder their ability to achieve substantial voltage gains. This paper proposes a transformative solution through the introduction of transformerless DC-DC converters. The innovative use of parallel charging and series discharging of two inductors with matched inductance during different phases of the switching cycle enables the desired voltage boost. This research offers a promising solution for applications requiring high voltage gains while emphasizing simplicity and efficiency in design. The proposed converter leverages a unique combination of circuit topology and control strategy, allowing for efficient voltage conversion without the need for complex duty ratio adjustments. The transformerless DC-DC converter with high step-up voltage gain, free from duty ratio modulation constraints, offers a promising solution for applications in renewable energy systems, electric vehicles, and other power-hungry devices. This research contributes to advancing the state-of-the-art in transformerless power conversion by introducing an innovative approach to achieve high voltage gain without the need for duty ratio modulation.

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ABBREVIATIONS AND NOMENCLATURE

DCM	Discontinuous conduction Mode
CCM	Continuous conduction Mode

CHAPTER I

1. INTRODUCTION

1.1 INTRODUCTION

Conventional DC-DC converters often rely on transformers to accomplish voltage transformation, but these components introduce complexities, weight, and cost. Moreover, achieving high step-up voltage gains conventionally involves intricate duty ratio modulation, demanding sophisticated control strategies. The proposed transformerless converter seeks to overcome these limitations, presenting a paradigm shift in the way high voltage gains are achieved. In the realm of power electronics, the quest for more efficient and compact DC-DC boost converters has become increasingly crucial to meet the growing demands of modern technologies. This project represents a significant leap forward in this pursuit by introducing a transformerless DC-DC boost converter, a novel solution designed to surmount the limitations inherent in conventional counterparts. The challenges faced by traditional boost converters, such as limitations in achieving substantial voltage gains due to power switch dynamics and component resistances, necessitate a paradigm shift in design. Our project proposes an innovative methodology that capitalizes on the parallel and series working of inductors during distinct phases of the switching cycle, thereby eliminating the need for a conventional transformer. This introduction establishes the context for an in-depth exploration of the theoretical underpinnings, analytical solutions, MATLAB simulations, and practical implementations integral to the success of this transformative approach. As we embark on this journey, our goal is to not only unravel the theoretical elegance of the proposed transformerless design but also to validate its practical feasibility through experimental validation. Furthermore, we envision its potential applications spanning diverse energy systems and electronic devices, underscoring the significance of this project in pushing the boundaries of power electronics innovation.

1.1.1 Objectives

- The primary objective of this research is to design, analyze, and implement a transformerless DC-DC converter
- To achieve high step-up voltage gain without relying on duty ratio modulation.
- To implement in MATLAB
- To develop a hardware model.

1.1.2 Scope of the Work

The future scope of the transformerless DC-DC boost converter project involves delving into advanced optimization strategies for heightened efficiency, exploring integration possibilities with smart grid systems and miniaturized electronic devices. Further research will focus on implementing advanced control strategies, expanding the converter's operational range, and enhancing fault tolerance and reliability. The converter's adaptability to diverse energy sources will be investigated for applications in hybrid energy systems and energy harvesting. Additionally, a comprehensive analysis of the environmental impact will be conducted, contributing to sustainable design practices. The project aims to contribute to industry standards for transformerless converters and explore avenues for commercialization, ensuring widespread adoption in the evolving landscape of power electronics.

CHAPTER II

2. PROJECT DESCRIPTION

2.1 OVERVIEW OF PROJECT

This project focuses on revolutionizing DC-DC boost converters by proposing a transformerless design to overcome inherent limitations. The innovative approach involves a meticulous blend of analytical solutions and MATLAB simulations. Through in-depth theoretical analyses, we explore the intricacies of achieving high step-up voltage gains while considering operational constraints. The project seamlessly integrates MATLAB simulations to validate and extend our theoretical framework, offering dynamic insights into the converter's performance. Join us as we showcase a holistic and cutting-edge solution that combines analytical rigor and computational simulations to advance the efficiency and design of power electronics systems.

2.2. MODULES OF THE PROJECT

The series and parallel working modules in the project design represent a strategic utilization of inductors during different phases of the switching cycle. This innovative approach enables the converter to achieve high step-up voltage gains without an excessively high duty ratio, contributing to the simplicity and efficiency of the overall transformerless design.

2.1.1 Module 1

During the switch-off period, the inductors operate in series, allowing the energy stored in each inductor to add up. This series configuration facilitates an additive effect, contributing to a higher overall voltage output during this phase of the switching cycle. Energy stored in the inductors is effectively combined, enabling a cumulative voltage boost. This series configuration optimizes the converter for efficient step-up voltage gains.

2.1.2 Module 2

In contrast, during the switch-on period, the inductors operate in parallel. This parallel configuration enables simultaneous charging of both inductors. By synchronizing their operation, the converter efficiently accumulates energy, preparing for the subsequent series discharge phase. Operating the inductors in parallel optimizes the charging process, ensuring a sufficient energy reserve for the subsequent series discharge. This parallel working contributes to the overall efficiency of the transformerless DC-DC boost converter.

CHAPTER III

3. DESIGN OF Transformer less DC-DC Converters with High Step-Up Voltage Gain

MATLAB Design:

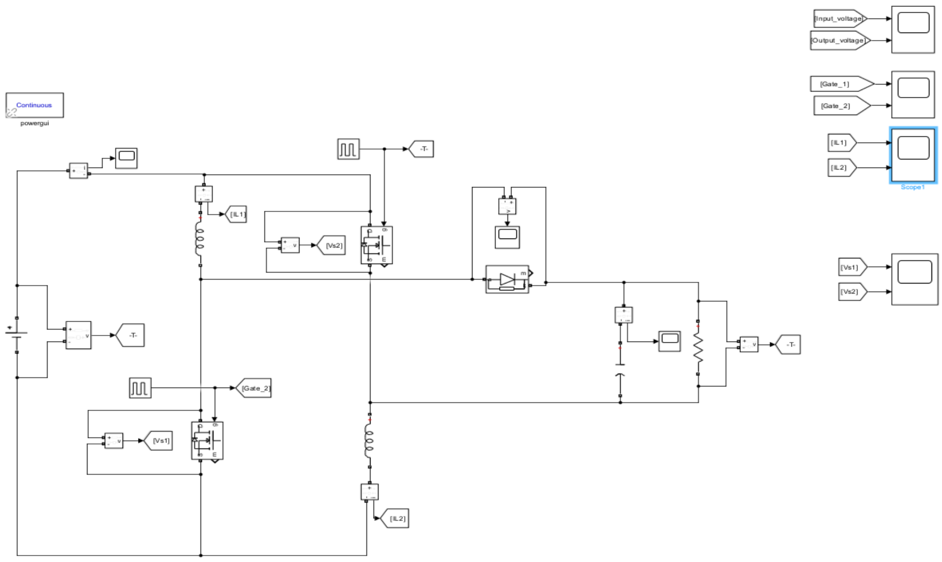

Figure 3.1 MATLAB Simulation

Hardware Design:

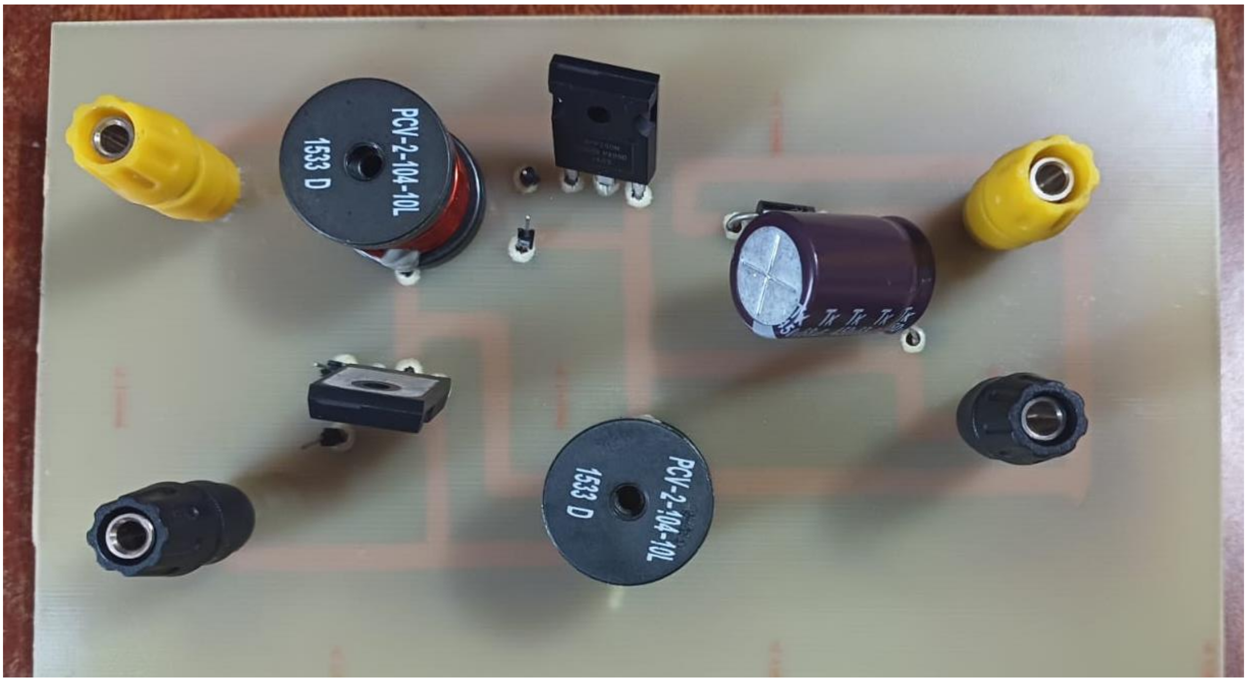

Figure 3.2 Hardware Converter

Mode 1:

$$\mathrm{V_{L1}} = \mathrm{V_{L2}} = \mathrm{V_L} = \mathrm{V_{in}}$$
$$\mathrm{V_c} = \mathrm{V_0}$$

Mode 2:

$$\mathrm{V_{in}} - \mathrm{V_{L1}} - \mathrm{V_{L2}} - \mathrm{V_0} = 0$$

$$2\mathrm{V_L} = \mathrm{V_{in}} - \mathrm{V_0}$$

$$V_L = \frac{V_{in} - V_0}{2}$$

By applying volt-sec balance theory

$$V_{in}D + \frac{V_{in} - V_0}{2}(1 - D)$$

$$2V_{in}D + V_{in} - V_{in}D = V_0(1 - D)$$

$$V_{in}(1 - D) = V_0(1 - D)$$

$$\frac{V_0}{V_{in}} = \frac{1 + D}{1 - D}$$

voltage stress across the switch ($\mathrm{V_S}$)

Applying KVL:

$$V_{in} - V_{L,T_{off}} - V_S = 0$$

$$V_S = V_{in} - V_{L,T_{off}}$$

$$V_S = V_{in} - \frac{V_{in}}{2} + \frac{V_0}{2}$$

$$V_S = \frac{V_0 + V_{in}}{2}$$

DCM operation

Mode 1

$$V_{L,T_{on}} = V_{in}$$

$$V_{L,T_{on}} = L\frac{di_L}{dt} = V_{in}$$

$$L\frac{\Delta i_L}{\Delta T} = V_{in}$$

$$\Delta i_L = \frac{V_{in}}{L}\Delta T$$

$$I_{L1P} = I_{L2P} = \frac{V_{in}}{L}DT\text{---------(1)}$$

Mode 2:

$$V_{L,T_{off}} = \frac{V_{in} - V_0}{2}$$

$$L\frac{di_L}{dt} = \frac{V_{in} - V_0}{2}$$

$$\Delta i_L = \frac{V_{in} - V_0}{2L}(D_2)T$$

$$-I_{L1P} = \frac{V_{in} - V_0}{2L}D_2T$$

$$I_{L2P} = I_{L1P} = \frac{V_0 - V_{in}}{2L}(D_2)T\text{ ----------(2)}$$

From 1 and 2

$$\frac{V_{in}}{L}DT = \frac{V_0 - V_{in}}{2L}D_2T$$

$$D_2 = \frac{V_{in}D_2\,L}{L(V_0 - V_{in)}}$$

$$D_2 = \frac{2DV_{in}}{V_0 - V_{in}}$$

$$I_{c0,avg} = \frac{-I_0(DT_S) + \frac{1}{2} - I_0(D_2T_S) - I_0(1 - D - D_2)T_S}{T_S}$$

$$I_{c0,avg} = \frac{\frac{1}{2}D_2T_SI_{LP} - I_0T_S}{T_S}$$

$$I_{c0,avg} = \frac{1}{2}D_2I_{LP} - I_0 = 0$$

$$\frac{D^2V_{in}^2}{L(V_0 - V_{in})f_s} = \frac{V_0}{R_0}$$

$$\frac{D^2V_{in}^2}{V_0(V_0 - V_{in})f_s} = \frac{Lf_s}{R_0} = \tau$$

Design of inductor

Mode 1:

$$V_{L,T_{on}} = V_{in}$$

$$L\frac{di}{dt} = V_{in}$$

$$L\frac{\Delta I_L}{T_on} = V_{in}$$

$$L = \frac{V_{inT_{on}}}{\Delta I_L}$$

$$T_{on} = \frac{L\Delta I_L}{V_{in}}$$

$Mode$ 2:

$$V_{l,T_{off}} = \frac{V_{in} - V_0}{2}$$

$$\frac{L(-\Delta I_L)}{T_{off}} = \frac{V_{in} - V_0}{2}$$

$$T_{off} = \frac{L\Delta I_L \cdot 2}{V_0 - V_{in}}$$

$$T_{on} + T_{off} = T = \frac{1}{f}$$

$$L\Delta I_L \left[\frac{1}{V_{in}} + \frac{2}{V_0 - V_{in}}\right] = \frac{1}{f}$$

$$L = \frac{1}{f} \cdot \frac{1}{\Delta I_L \left(\frac{1}{V_{in}} + \frac{2}{v_0 - V_{in}}\right)}$$

$$L = \frac{1}{f\Delta I_L \left(\frac{V_0 + V_{in}}{V_{in}(V_0 - V_{in})}\right)}$$

3.2 **DESIGN SPECIFICATIONS**

S.NO	COMPONENTS	RATING	COST
1	Inductor (2)	100mH, 10A	400
2	Capacitor (1)	68µF, 450V	350
3	MOSFET (2)	IRF250N	300
4	DIODE (1)	MUR460	100

Table 3.1 Design specification

CHAPTER IV

4. PROJECT DEMONSTRATION

4.1 INTRODUCTION

In this project demonstration, we present a transformerless DC-DC boost converter design addressing challenges in conventional converters. Our approach involves a comprehensive analytical solution, delving into theoretical insights on voltage gains and operating conditions. Complementing this, MATLAB simulations validate and extend our theoretical framework, offering dynamic insights into the converter's performance.

4.2 ANALYTICAL RESULTS

Design of inductor:

$$VL, T_{on} = V_{in}$$

$$L\frac{di}{dt} = V_{in}$$

$$L\frac{\Delta I_L}{T_{on}} = V_{in}$$

$$T_{on} = L\frac{\Delta I_L}{V_{in}}$$

$$V_{L,T_{off}} = \frac{3V_{in} - V_0}{2}$$

$$T_{off} = \frac{2L\Delta I_L}{V_0 - 3V_{in}}$$

$$T_{on} + T_{off} = T = \frac{1}{f}$$

$$L\Delta I_L\left[\frac{2}{V_0 - 3V_{in}} + \frac{1}{V_{in}}\right] = \frac{1}{f}$$

$$L = \frac{1}{f\Delta I_L\left(\frac{2}{V_0 - 3V_{in}} + \frac{1}{V_{in}}\right)}$$

$$L = 92.64\mu H$$

***Design of capacitor*:**

$$i_c = i_{in}$$

$$\Delta V_C = \frac{1}{C} I_{in} T_{off}$$

$$C = \frac{I_{in} T_{off}}{\Delta V_C}$$

$$C = \frac{I_{in}(1 - D)T}{\Delta V_C}$$

$$C = \frac{I_{in}(1 - D)}{\Delta V_C f}$$

$$= \frac{3.33 \cdot (1 - 0.73)}{0.12 \cdot 100 \cdot 10^3}$$

$$C = 74\ \mu F$$

4.3 SIMULATION RESULTS

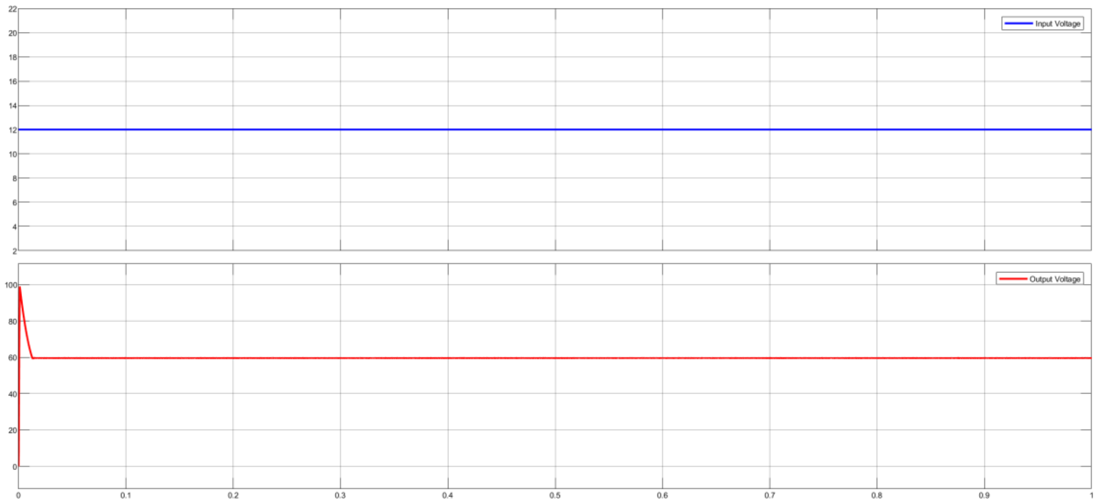

Figure 4.1 Input and output voltage graph

The above picture demonstrates the Input and output voltage graph obtained from the MATLAB which is 12V(blue) and after stepup of 60V(red) respectively as expected with no loss.

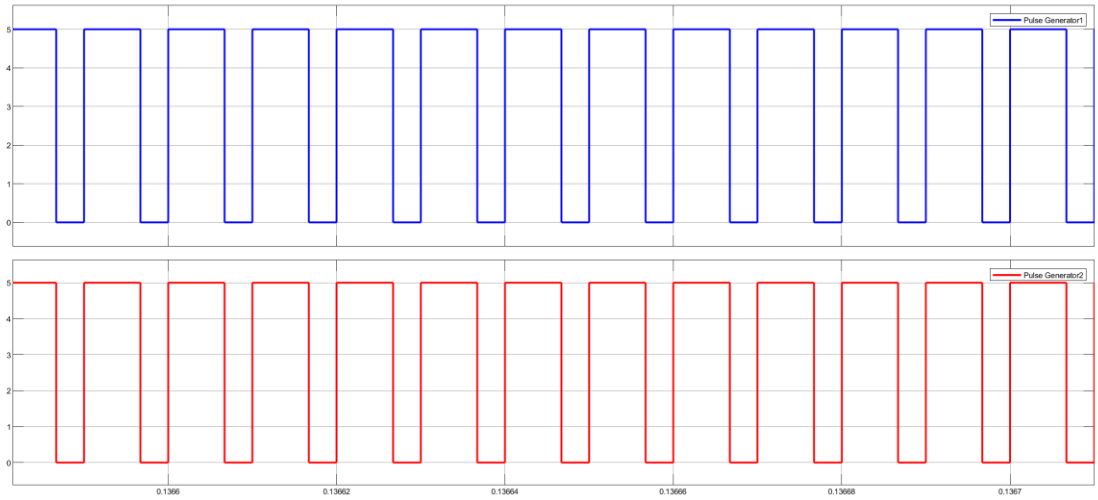

Figure 4.2 Pulse Generator

The above picture demonstrates the pulse generator signal for MOSFET with Amplitude:5, Pulse Width (% of period):67, Period (secs):1e-05.

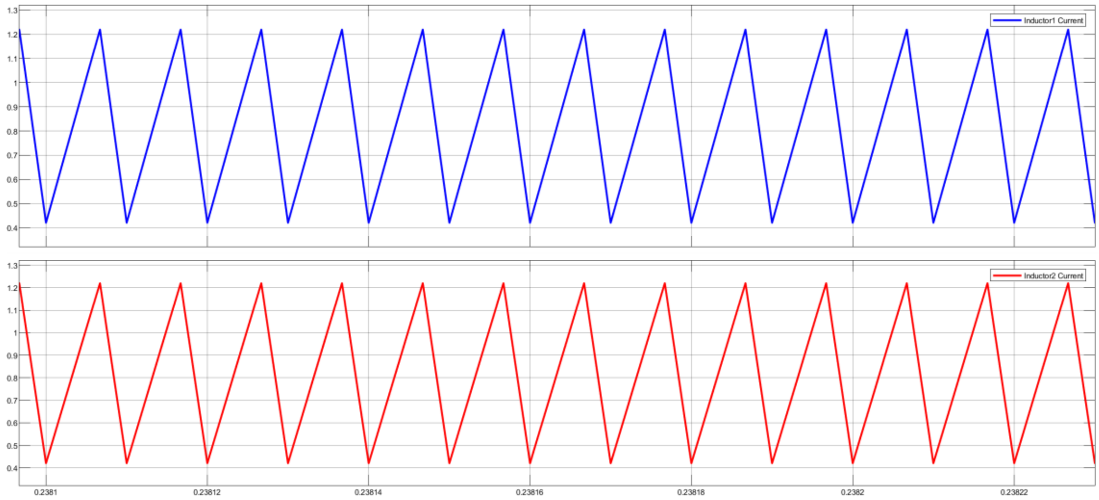

Figure 4.3 Inductor current

The above picture demonstrates the Inductor current both inductor1 and inductor2.

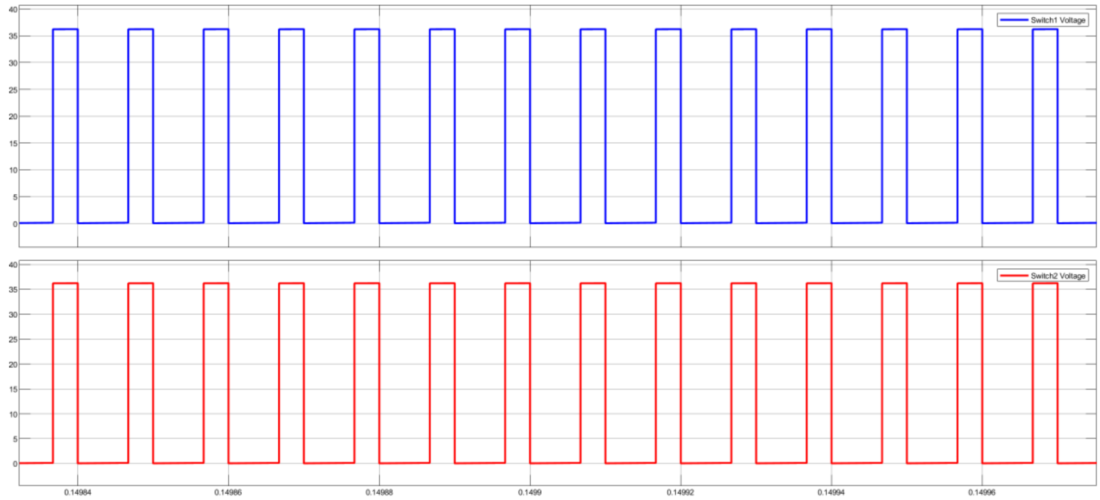

Figure 4.4 Switch voltage

The above picture demonstrates the switch voltage of both MOSFET's.

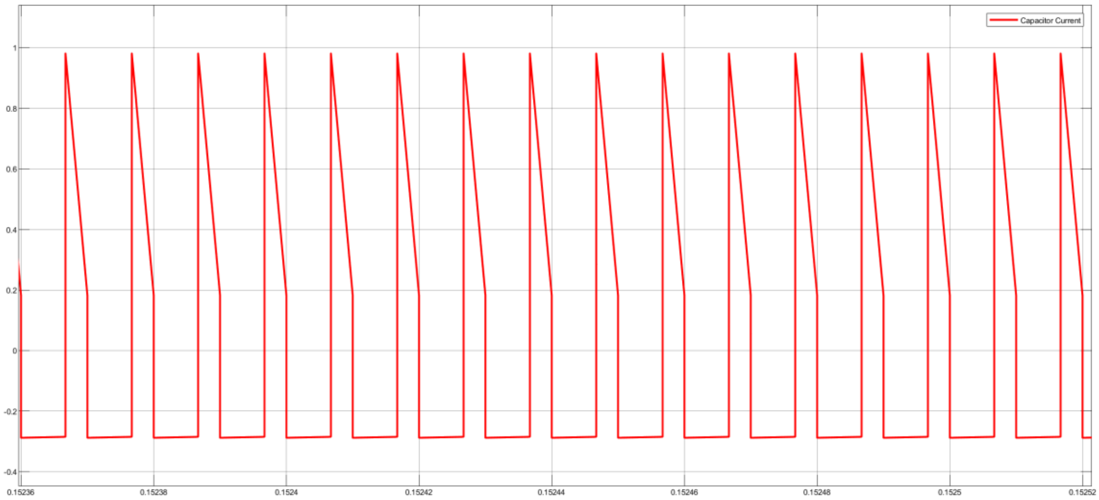

Figure 4.5 Capacitor current

The above picture demonstrates the current through the capacitor.

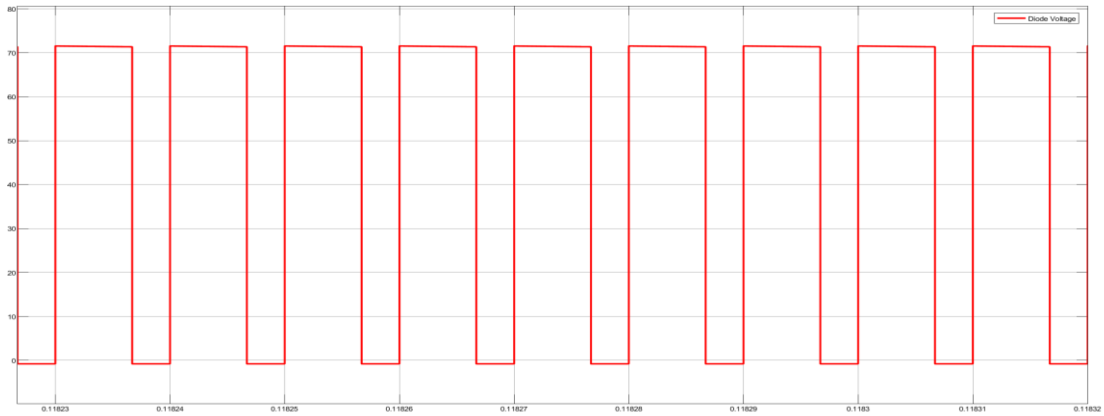

Figure 4.6 Diode voltage

The above picture demonstrates the voltage across the diode.

CHAPTER V

5. CONCLUSION

In conclusion, the development of a transformerless DC-DC converter to achieve high step-up voltage gain without duty ratio modulation represents a significant stride toward enhancing the efficiency and simplicity of power conversion systems. Through an exhaustive exploration of innovative circuit topologies and control strategies, this research has successfully demonstrated the feasibility of achieving substantial voltage upscaling without the traditional reliance on duty ratio adjustments. The theoretical analysis provided a foundational understanding of the operational principles, enabling the formulation of a robust converter design. The experimental validation on a physical prototype substantiated the theoretical predictions, confirming the practical viability of the transformerless converter. Comparative studies showcased the advantages over conventional transformer-based converters and other transformerless designs, emphasizing the simplicity, reduced control complexity, and enhanced reliability of the proposed approach..

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