DC – DC CASCODE BUCK – BOOST CONVERTER USING CLOSED LOOP PI CONTROLLER

Submitted by

Vedant Nath	Samarth Mittal	Manyu Garg
200929005	200929016	200929070

Under the guidance of

Dr. Niraj Kumar Dewangan

Assistant Professor

Department of Mechatronics

MIT Manipal

in partial fulfilment of the requirements for the award of the degree of

BACHELOR OF TECHNOLOGY
IN
MECHATRONICS

DEPARTMENT OF MECHATRONICS

MANIPAL INSITUTE OF TECHNOLOGY

(A Constituent of Manipal Academy of Higher Education)

MANIPAL – 576104, KARNATAKA, INDIA

November 2022

MANIPAL INSTITUTE OF TECHNOLOGY
MANIPAL
(A constituent unit of MAHE, Manipal)

DEPARTMENT OF MECHATRONICS

Manipal

November 6, 2022

CERTIFICATE

This is to certify that the mini project titled **DC – DC Buck Boost Converter using Closed Loop PI Controller** is a record of work done by **Vedant Nath (200929005), Samarth Mittal (200929016)** and **Manyu Garg (200929070)** submitted for Drives, Control and Motors Lab during the academic year 2022 – 2023.

Dr. NIRAJ K DEWANGAN
Assistant Professor
Dept. of Mechatronics
MIT Manipal

Dr. VIJAY BABU KOREINA
Lab Coordinator
Dept. of Mechatronics
MIT Manipal

ACKNOWLEDGEMENTS

At the outset, the team would like to take this opportunity to thank everyone who assisted, supported, and inspired us throughout the course of the project to make this a success. They were there to help us at every turn, and it was their motivation that made it possible for us to complete assignments successfully.

Your valuable guidance and suggestions helped us in various phases of the completion of this project. The ream will always be thankful to you in this regard.

Additionally, the team would like to express our gratitude to the Manipal Institute of Technology for accepting our project in our area of competence. We also like to express our gratitude to our parents for their help and inspiration throughout the course of our undertaking.

ABSTRACT

Cascode converters have the ability to provide very high output voltage gain in a single stage, as contrast to many cascaded converters with a low duty ratio. This study covers in detail the steady-state analysis and operational theory. Discussion and comparison of the voltage increase are made with typically Boosted, Buck-Boost Converter, etc. A 50W cascode converter laboratory experiment has been constructed to test the simulation and experimental findings after a dynamic study of the entire circuit. The cascode converter employs two buck-boost converters. All of them are connected by one active switch. The input voltage is supplied by the source of the lower semi-dc stage. The top semi-input stages from the dc source are connected in series with the lower semi-output stage. The converter's overall output voltage is therefore equal to the sum of the output voltages from the two cascode-enabled semi-stages. As a result, a dc-dc converter with a large voltage gain is created without employing an overly high duty ratio. The converter's output voltage is set to the reference value using a PI controller.

A P.I Controller is a feedback control loop that calculates an error signal by taking the difference between the output of a system, which in this case is the power being drawn from the battery, and the set point.

LIST OF FIGURES

TABLE OF CONTENTS

CHAPTER 1
Introduction

Two Buck-Boost Converters are used to create a DC-DC Cascode Buck-Boost Converter with an IGBT as the active switch. The two Buck-Boost Converters have the titles top semi-stage and bottom semi-stage. Both the input voltage for the top semi-stage and the input voltage for the bottom semi-stage converter are provided directly by a DC source. The output voltages from the top and bottom semi-stages are added to determine the output voltage of the bottom semi-stage converter. Therefore, the recommended Cascode Converter can be used to achieve very high output voltage gain in a single Stage rather than using a larger number of cascaded converts without a high duty ratio.

A DC-to-DC converter known as a "buck-boost converter" has an output voltage magnitude that is either more than or less than the input voltage magnitude. It is utilised to "step up" the DC voltage, much like an AC transformer. Utilizing a single inductor in place of a transformer is equivalent to using a flyback converter. Buck-boost converters are two separate topologies. Choppers are another name for DC-DC converters. Here, we'll look at the Buck Boost converter, which, depending on the duty cycle, D, can function as a DC-DC Step-Down or Step-Up converter.

1.1 Purpose:

For a moderate duty cycle, a very high voltage gain cannot be achieved in a single stage using conventional converters like Boost and Buck-Boost. Extremely high duty ratios can result in significant EMI and serious reverse recovery issues. They are mostly caused by the losses brought on by diode voltage drop, output filter capacitance, and input inductance. There are other converter topologies that offer high voltage gain, but Cascode Converter offers high voltage gain with a moderate duty cycle and good efficiency. The losses are decreased by the single active switch used in cascode converters.

1.2 Ethics:

The cornerstones of environment ethics in engineering are justice and sustainability, sufficiency and compassion, solidarity and involvement, and justice and sustainability. This lesson demonstrates how environmental issues push us to enlarge on these ideas in order to consider the welfare of the environment and our responsibilities as responsible humans.

1.3 Safety:

• Provides a tool for ISO 26262 functional safety analysis activities

• Integrates functional safety analysis and development activities

• Ensures consistency and rich traceability

• Supports ASIL determination and decomposition as well as safety goal and requirements management6

• Integrates with existing tools

• Generate reports (e.g., safety concept)

1.4 Risks:

• The MATLAB® Web App Server™ has no specific mechanism to prevent HTTP request capture and replay.

• The development version of MATLAB Web App Server has no mechanism for authentication or authorization other than HTTPS.

• Any user with access to the network can run any application created with this software and read any data the application is authorized to access.

CHAPTER 2

Software and Components used in Simulation

The Software and Components used in the simulation are as follows:

2.1 Software and toolboxes:

▪ MATLAB

▪ Simscape and Simscape Electrical toolboxes

▪ Control System toolbox

▪ Math toolbox

2.2 Variable Inductor Block

The Variable Inductor block symbolizes a linear time-varying inductor. The current source is an inductor with discrete variables. The impedance is specified by the Simulink input signal. An inductance value that is negative is possible.

The RF Blockset determined constant for the minimum inductance (Lmin) is unrelated to the Simulink control signal. Two electrical terminals are on the block. The RF Blockset signal and Simulink control signal each have their own terminal.

2.3 IGBT Block

A three-terminal power semiconductor known as an insulated-gate bipolar transistor (IGBT) is primarily employed as an electronic switch and has evolved over time to combine high efficiency and quick switching. It has a metal-oxide-semiconductor gate arrangement that controls four alternating layers (P-N-P-N). To imitate an IGBT, connect a switch to a resistor, an inductor, and a DC voltage source in series with a logical signal ($g > 0$ or $g = 0$).

The IGBT is utilised in switching amplifiers in sound systems and industrial control systems because of its ability to produce complicated waveforms with pulse-width modulation and low-pass filters.

2.4 Variable Resistor Block

The variable resistor block controls the output of the established feedback circuits in the RF Block with the aid of Simulink-controlled resistance in ohms. The minimum resistance (Rmin) constant for the RF Block set is independent of the Simulink control signal. The block has two electrical connections. The RF Blockset signal and Simulink control signal each have their own terminal.

A Simulink library and simulation engine called RF Blockset is used to create RF systems. Models of mixers, amplifiers, S-parameter blocks, and other fundamental building blocks are included. The architecture of wireless transceivers used in communication and radar systems can be designed with the help of RF Blockset. By connecting these building components, it is possible to emulate at the system level the operation of RF front ends.

2.5 Slider Gain Block

During simulation, the Slider block adjusts the connected block parameter's value. For instance, you might link your model's Slider block to a Gain block so that you could change its value during simulation.

The Slider Gain block's scalar gain computations can be changed while the simulation is running. Adjust the gain with the slider control.

2.6 Capacitor Block

Capacitors are employed in a number of ways in electronic circuits because of their crucial ability to block DC current while passing AC current. Most electronic device fault noises are caused by high-frequency AC current components. For noise reduction, capacitors are essential.

DC current ceases to flow through the capacitor as soon as the power source has fully charged it. Because an insulator separates the electrode plates of the capacitor, no DC current can flow unless the insulator breaks down, stopping the DC current.

The polarity of an AC current alternates between positive and negative on a regular basis. As the polarity of the current changes, capacitors are continuously charged and discharged, allowing AC current to pass through.

The Variable Capacitor block's Simulink-controlled capacitance is used to adjust the output of feedback circuits. The smallest value of capacitance is a Block set declared as constant, irrespective of the Simulink control signal (Cmin). The block has two electrical connections. Both the Block set signal and the Simulink control signal have their own terminals.

2.7 Ideal Diode Block

The Ideal Semiconductor Switch block simulates a flawless semiconductor switching device. Because the gate-cathode voltage is greater than the predetermined threshold voltage, the ideal semiconductor switch is in the state. If not, the device is turned off. When activated, the anode-cathode pathway behaves like a linear resistor with an on-resistance. The anode-cathode route behaves like a linear resistor and has a low off-state conductivity.

2.8 Constant Block

A real or complex constant value signal is produced by the Constant block. To supply a steady signal input, use this block. The Constant block generates a real or complex constant value signal. Use this block to give a continuous signal input.

2.9 Pulse Generator Block

The Pulse Generator block generates square wave pulses at regular intervals. The block waveform parameters Amplitude, Pulse Width, Period, and Phase Delay determine the shape of the output waveform.

The Pulse Generator block can output any real data type as a scalar, vector, or matrix signal. When defining the waveform parameters, utilise scalars to have the block generate a scalar signal. When defining the waveform parameters, use vectors or matrices, as appropriate, to make the block emit a vector or matrix signal. Each waveform parameter has an impact on the related output signal parameter.

For instance, the amplitude of the first element of a vector output pulse is determined by the vector amplitude parameter's first element. After scalar expansion, each waveform parameter must have the same size. The output's data type matches that of the Amplitude parameter's data type.

2.10 DC Power Block

To power a test object, such as a circuit board or electronic product, a DC power supply supplies direct current (DC) voltage. The DC Voltage Source block embodies a perfect DC voltage source. The positive terminal is identified on one port by a plus sign. The amplitude of the source is given in volts (V). The norm is 100V.

2.11 Voltage Measurement Block

The electrical potential difference between two locations in an electrical or electronic circuit is known as voltage. The voltage measurement block immediately measures the voltage between two electrical nodes.

It calculates the potential energy needed to generate an electric current in an electrical conductor from an electric field. The signal provided by the output can be used by other Simulink blocks.

2.12 Sum Block

The values that are sent to the Sum block are added or subtracted. Interchangeable blocks are used for Add, Subtract, The Sum of Elements, and Sum. This block's inputs can be scalar, vector, or matrix data. Additionally, it has the capacity to collapse and add a signal's constituent parts. You can describe the operations of the block using the plus (+), minus (-), and spacer (|) signs in the List of signs argument.

The Sum block executes the required operations after converting the input data type to its accumulator data type. The block applies the provided rounding and overflow modes to convert the result to the output data type.

2.13 PWM Generator

A technique for converting an analogue signal into a single digital bit is pulse width modulation (PWM). Duty cycle and frequency are the two key factors that determine the behaviour of a PWM signal. When creating a square wave, a pulse width modulation (PWM) signal generator changes the duty cycle while maintaining a constant period.

It is utilised as a fundamental algorithm for photovoltaic solar battery chargers, as well as for power control of electronic equipment like motors and the transmission of information by encoding a message into a pulsing signal.

The PWM Generator block is used to implement a PWM generator. The pulse width modulation method controls the transfer of power from one electrical component to another by quickly alternating between complete power transfer and no power transfer.

2.14 Current Measurement Block

The passage of electric charge is known as electric current. The current measuring block is used to measure the instantaneous current passing through any electrical block or connection line. The Simulink signal supplied by the Simulink output can be used by other Simulink blocks.

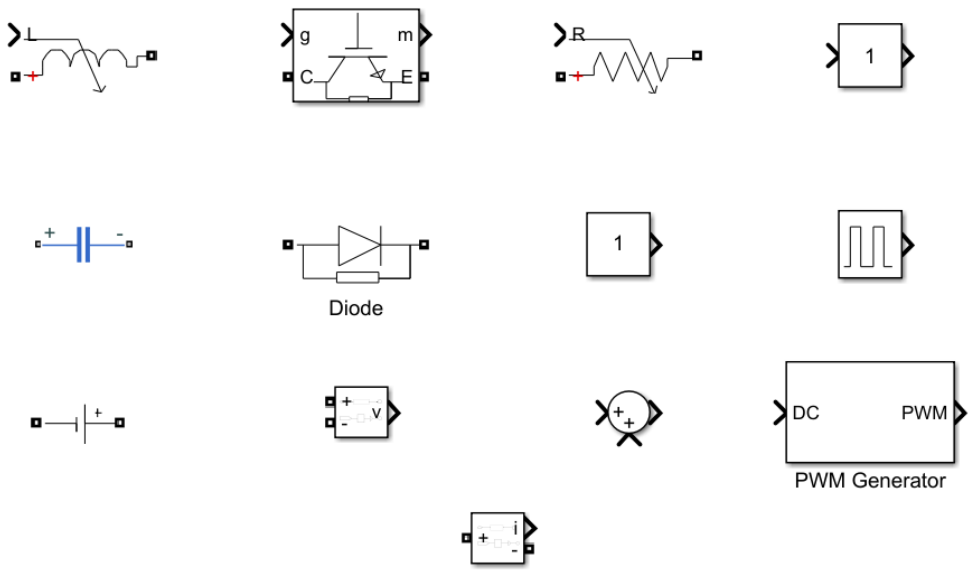


Fig 2.1 Components utilized in the project

CHAPTER 3

Literature Review

3.1 PI Controller

In this study, the output voltage of the DC-DC Cascode converter is managed by a PI controller. The industrial and benchmark is the open loop DC-DC Cascode converter. The set point for controlling the output voltage is voltage. To create the input pulse for the active switch IGBT, the error signal is fed to the PI Controller, and the output of the PI Controller is compared with a repeating sequence of 10 KHz.

The needed variable is often kept near the set point or the value of the reference point by the controller. The error signal, which is the difference between the output and the reference, is typically examined by the feedback control system to accomplish this. In response to the error, the controller tries to set the actuator's signal.

$$u(t) = K[e(t) + \frac{1}{T_i}\int^{t} e(s)ds]$$

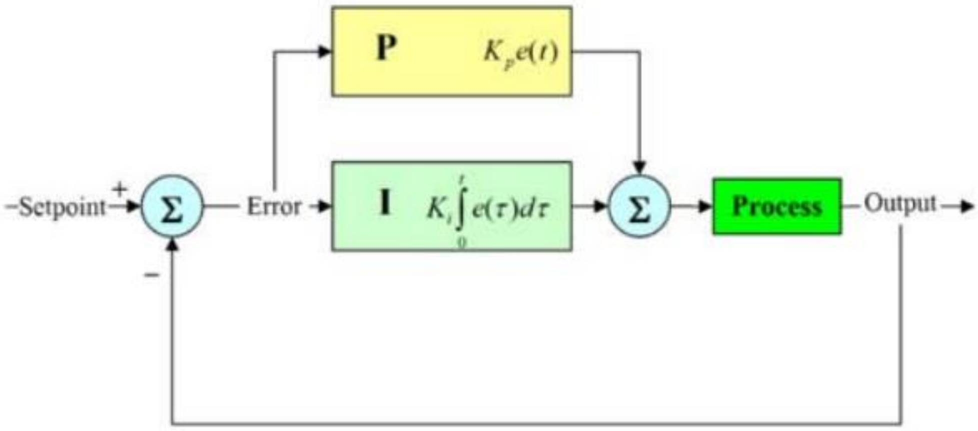


Fig 3.1 Closed Loop PI controller

3.2 Use of Cascode

As the number of stages between the source and the load are increased, the efficiency of the converter reduces due to high switching losses associated with the high frequency active switch, since the cascode converters have a single active switch, the losses are reduced. There are other converter topologies that offer high voltage gain, but the cascode converter offers high voltage gain with a moderate duty cycle and great efficiency.

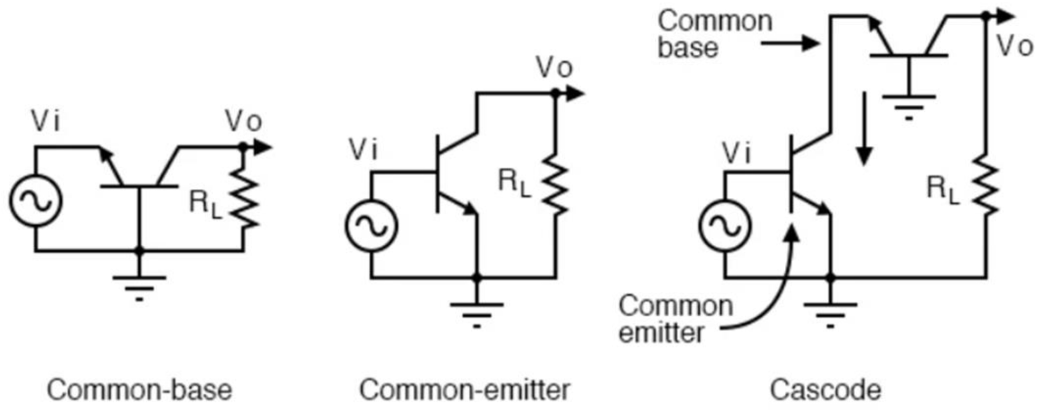


Fig 3.2 Circuit Diagram of Cascode

3.3 Buck – Boost Converter

A DC-to-DC converter known as a "buck-boost converter" has an output voltage magnitude that is either more than or less than the input voltage magnitude. It is utilised to "step up" the DC voltage, much like an AC transformer.

Utilizing a single inductor in place of a transformer is equivalent to using a flyback converter. Buck-boost converters are two separate topologies.

Choppers are another name for DC-DC converters. Here, we'll look at the Buck Boost converter, which, depending on the duty cycle, D, can function as a DC-DC Step-Down or Step-Up converter.

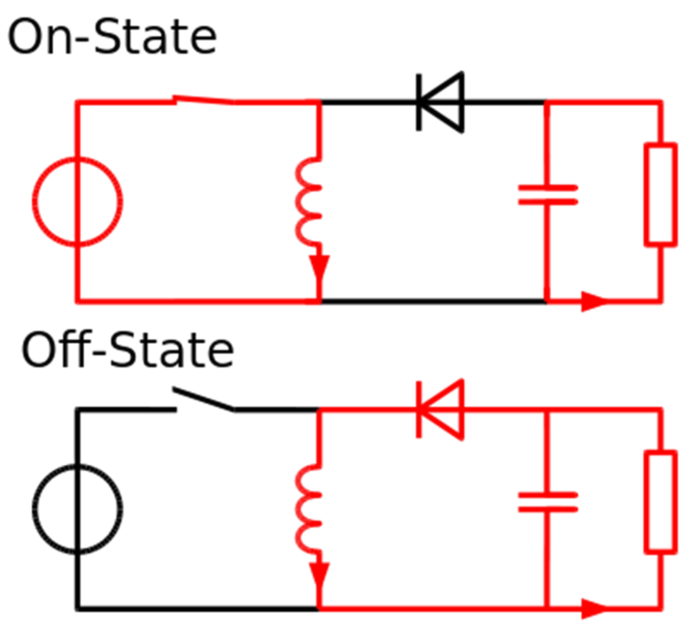


Fig 5.3 Buck Boost Circuit

CHAPTER 4

Construction/ Working Process

The toolboxes had to be empty of all required blocks before any components could be attached. Following the collection of all necessary components, the circuit is assembled in accordance with the Circuit Diagram (fig.3.1). 200 ohms is the set value for resistance, 3 milli and 16 milli for inductance, and 100 micro and 200 micro for capacitance, respectively.

4.1 Summary:

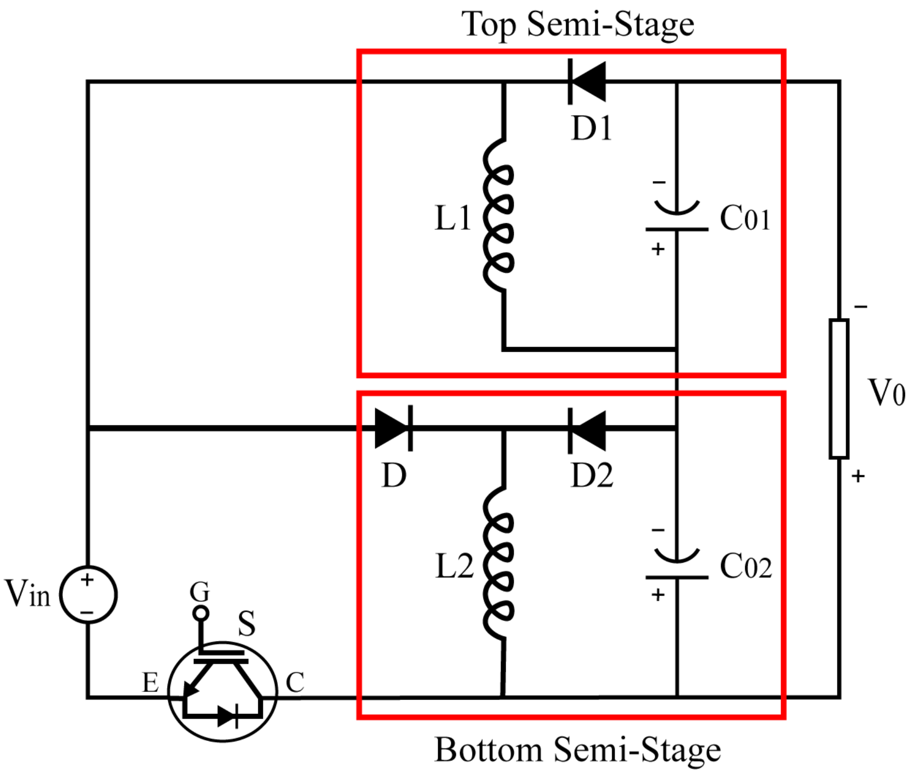


Fig 4.1 Circuit Diagram of Dual Buck Boost

One switch (IGBT S), one input, two reverse diodes (D, D1, and D2), an inductor (L1 and L2), and filter capacitors make up the majority of the proposed converter circuit (C1 and C2). The cascode converter is built from two Buck-Boost Converters and an active switch (S).

These designations refer to the top and bottom semi-state Buck-Boost Converters, respectively. The input DC supply serves as the input to the bottom semi-stage converter, and the output voltage of the bottom semi-stage converter serves as the input to the top semi-stage. Thus, the output voltages of each individual semi-stage converter are added to determine the overall output voltage.

A PI controller is then used to control the DC-DC Cascode converter's output voltage. The reference voltage serves as the set point for setting the output voltage in the plant's open-loop DC-DC cascode converter. The error signal is sent to the PI Controller, whose output is then compared with a repeating sequence of 10 kHz to provide the input pulse for the active switch IGBT. The controller frequently maintains the variable's value close to the set point or the value of the reference point. This is normally done by the feedback control system looking at the error signal, which is the difference between the output and the reference. The controller tries to set the actuator's signal in response to an error.

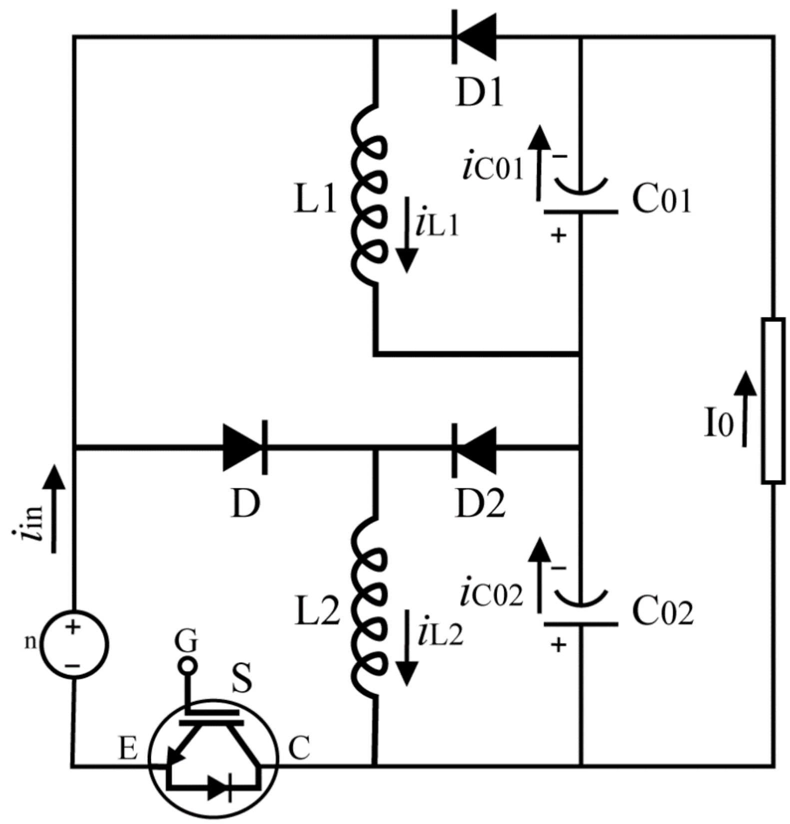


Fig 4.2 Working of a Dual Buck Boost circuit

CHAPTER 5

Simulated Output

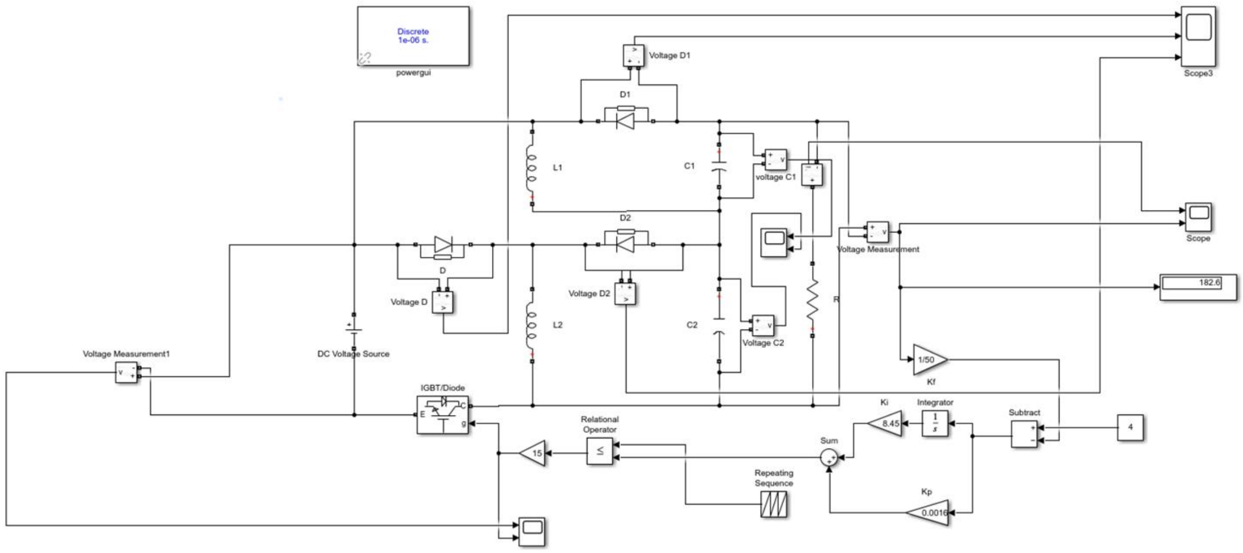


Fig 5.1 Circuit diagram

The findings of the dynamic analysis are validated by simulating the Cascode converter in the proposed circuit using MATLAB/Simulink. The simulation of the Cascode converter uses the input and output values as follows:

Vin is 50 V, V0 is 200 V, Pout is 200 W, R is 200 Ohm, and f = 10 KHz is the switching frequency. While the inductors have values of L1=16mH and L2=3mH, the output capacitors have values of C01=C02=100F. Figs. 5.1 and 5.2 show the various waveforms for simulated Cascode converters. Using MATLAB/Simulink, Figure 3.1 simulates a closed-loop Cascode BuckBook Converter with a feedback gain of 1/50 and a 4V reference voltage. In the MATLAB/Simulink simulation, the values of Kp and Ki are calculated and used. Kp = 0.0016 and Ki = 8.45 are the figures.

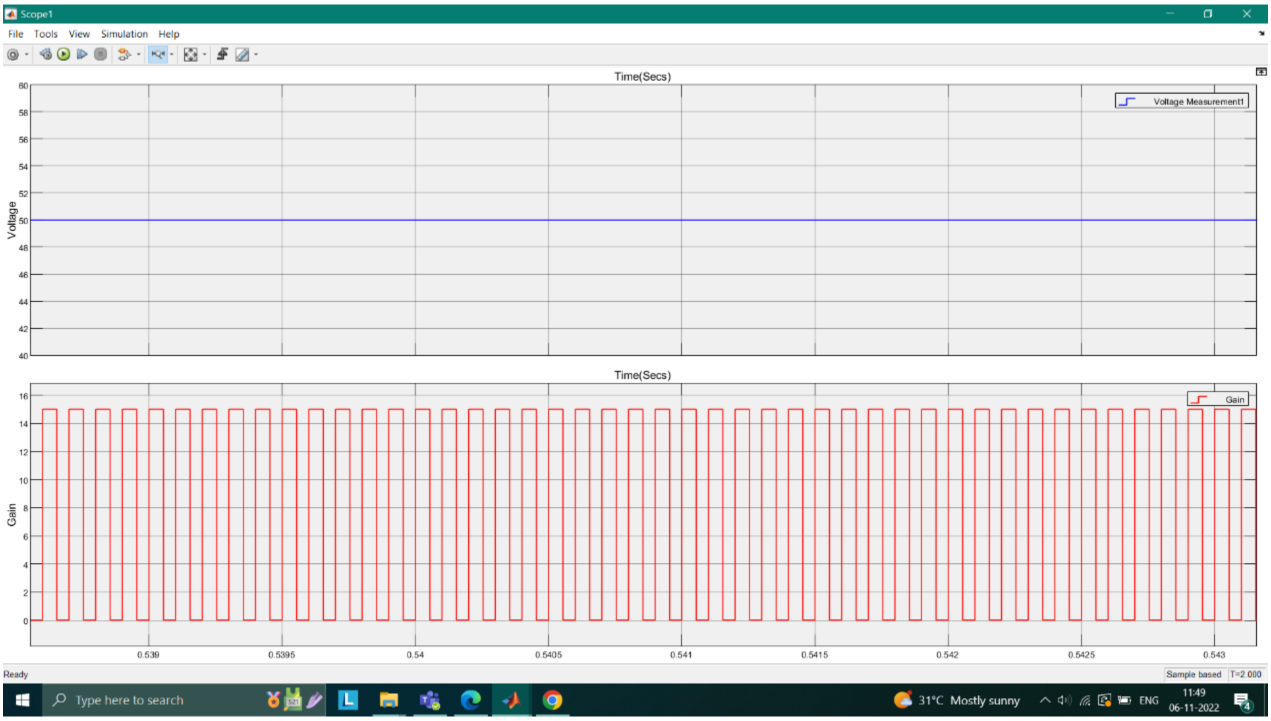


Fig 5.2 Input and Gain

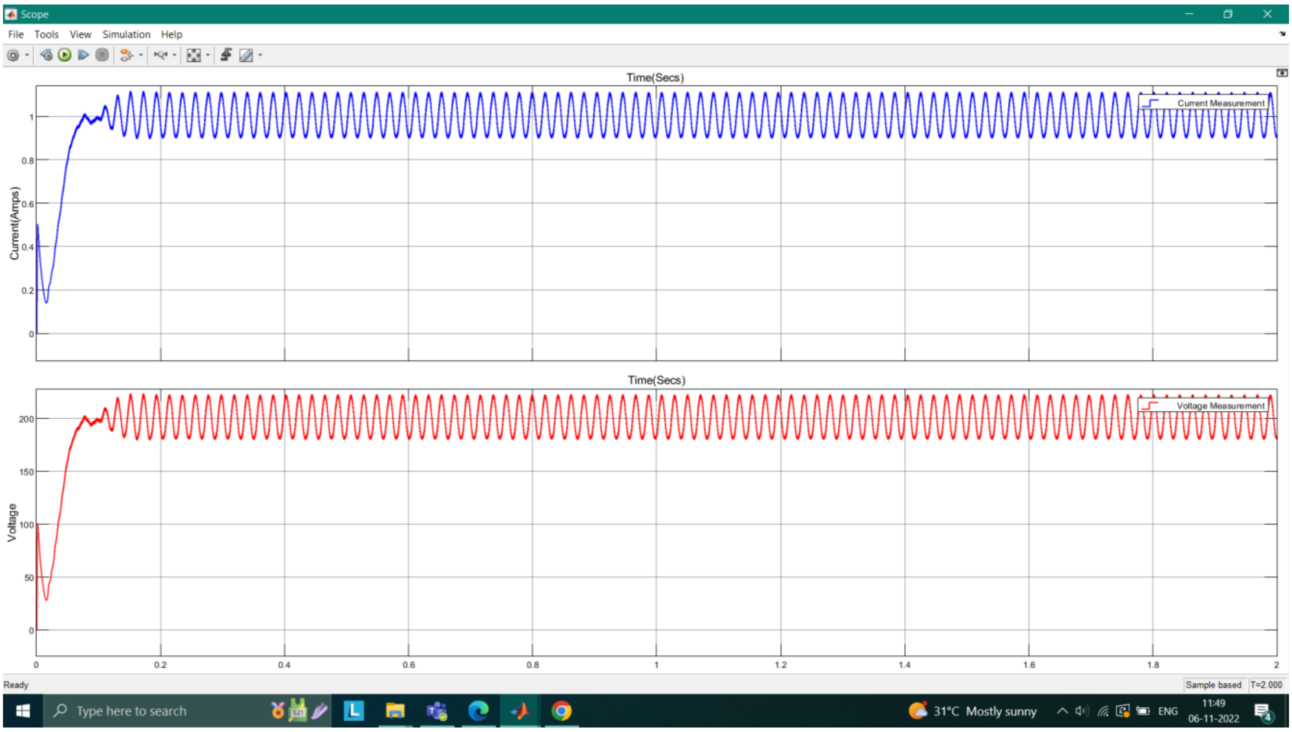


Fig 5.3 Output Current and Voltage

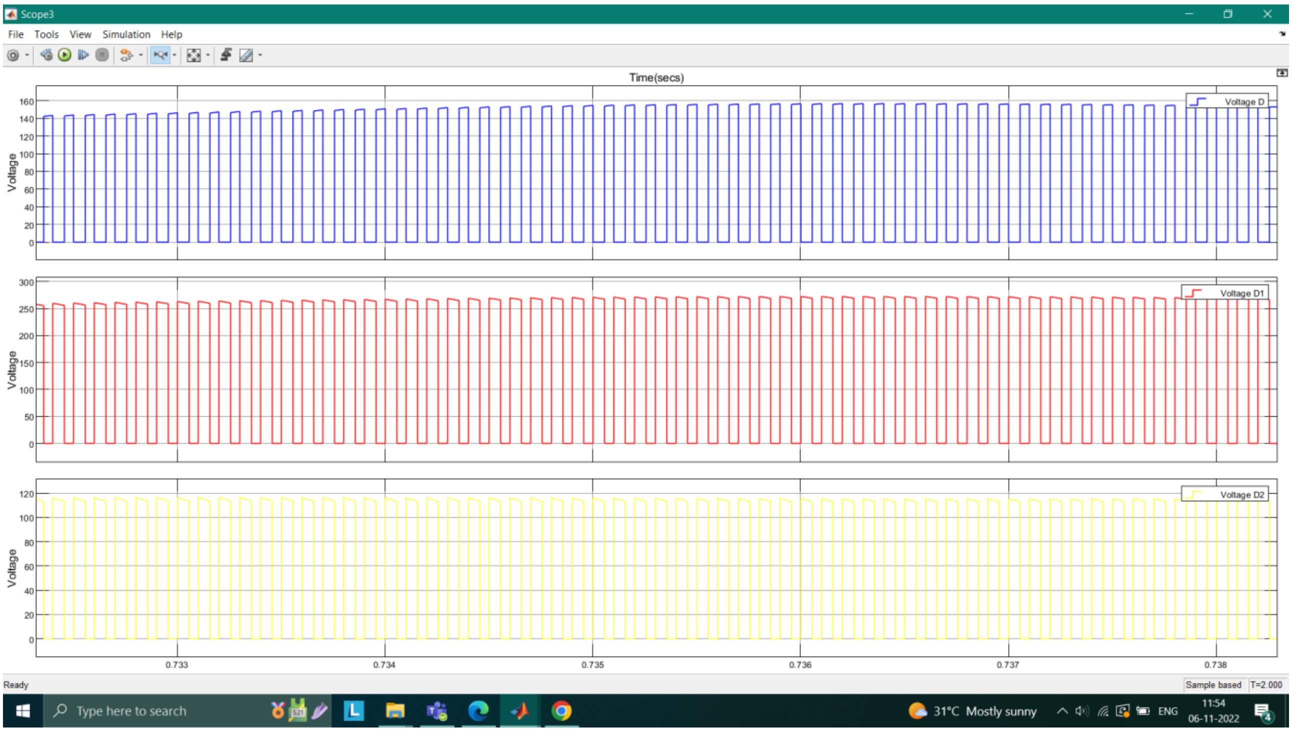
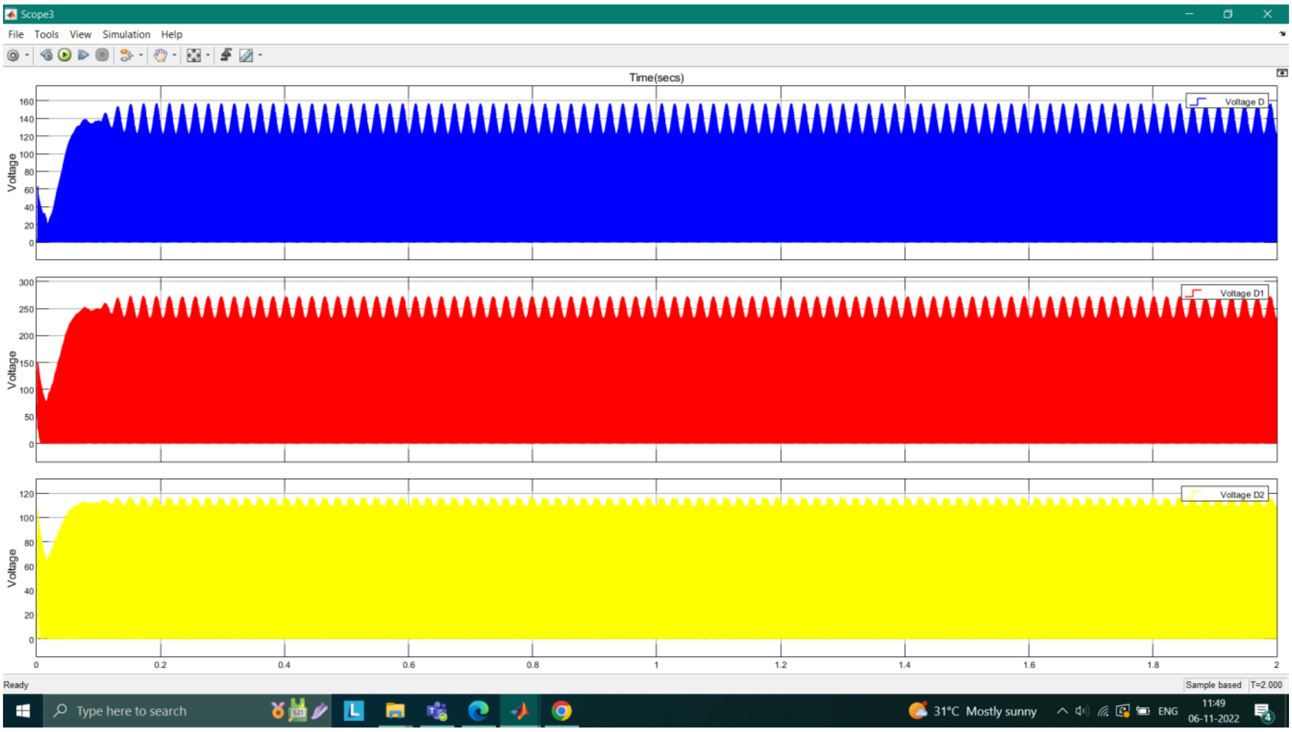


Fig 5.4 and Fig 5.5 Voltage Across 2 different diodes



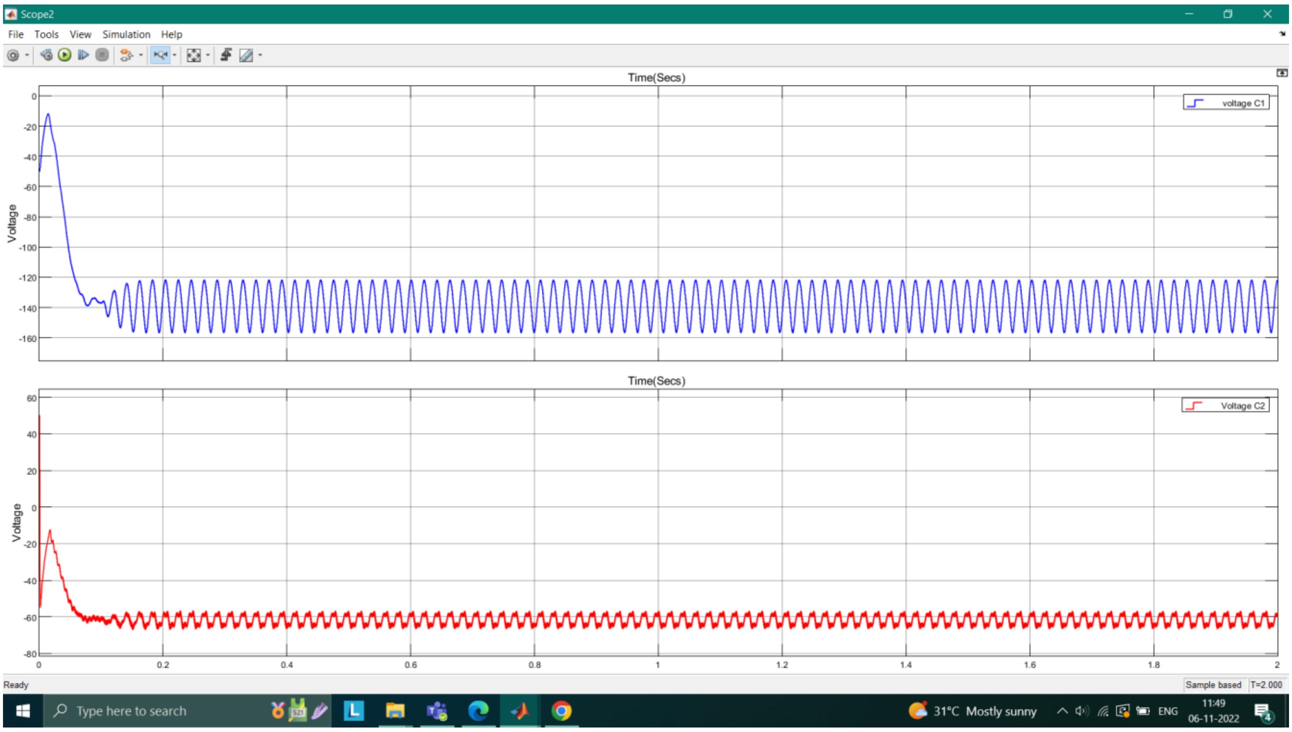


Fig 5.6 Voltage across Capacitor C1 and C2

CHAPTER 6

Conclusion and Application

To validate the findings of the theoretical steady state analysis used to study the proposed DC-DC Cascode converter, a prototype 50W Cascode Converter with a medium duty ratio is constructed in the lab using the circuit parameters L1=16mH and L2 = 3mH for the inductors, C01 = C02 = 100µF for the output capacitors, and R=200 ohm for the load resistance.

There has been set a reference voltage of 200V. Using a PI controller with the values Kp = 0.0016 and Ki = 8.45, the voltage output is managed.

It should also be noted that if the duty ratio is higher than 0.39, the voltage gain offered by the cascode converter will be greater than that of the boost converter. If the duty ratio is less than or equal to 0.2929, and if it is more or equal to 0.2929, the cascode converter can be employed as either a boost or a buck.

Due to the high-frequency operation and sharing of two inductor currents, the converter's size shrinks. The size of the converter decreases as a result of the high frequency operation and sharing of two inductor currents. In applications like hybrid vehicles, battery-powered vehicles, solar power applications, wind generator power applications, DC motor speed control applications, etc., the cascode converter can be used.

PI Controller is employed to control output voltage by controlling the input pulse width of active switch in transient as well as steady stage of the converter.

Cascode converter has several uses in real world and is commonly used in applications like:

- Hybrid Vehicle,
- Battery Powered Vehicles
- Solar Power applications
- Wind generator power applications
- DC motor speed control applications, etc.

REFERENCES

[1] Farhath K P, B Jayanand, “Transformerless high step-up DC-DC Cascode Converter with maximum power point tracking”, in IEEE International Conference on Power, Instrumentation, Control and Computing (ICPICC15), 2015.

[2] Z Johnson, N Mc Fowland, L Muller, K Petreson, J Jensby, “High gain DC-DC conversion for parallel photovoltaic arrays”, In 28th Annual IEEE Conference (APECE13), pp.2871-2875, 2013.

[3] Sharad W, Mohod, Abhijit V, Padgavhankar, “Closed Loop Digital Controller of DC-DC Converter for Renewable Energy Source (PV Cell)”, in International Conference on Renewable Energy and Sustainable Energy (ICRESE13), pp. 112-116, 2013.

[4] N Sivasankar , S Gayathri , S Vishnupriya, “Design and Simulation of Open and Closed Loop control for Transformerless DC–DC Buck-Boost Converter using Switched-Capacitor Structure”, in International Conference on Power, Energy and Control (ICPEC13), pp.320-324, Feb 6-8, 2013.

[5] Chi Jen Huang, Ying-Chun Chuang, Yu Lung Ke, “Design of Closed-loop Buck-boost Converter for LED Driver Circuit”, in IEEE Industrial and Commercial Power Systems Technical Conference (I&CPS), pp.1-6, May 1-5, 2011.

[6] Liang Jye, Shu Tsomg Juu Liang, Lung Sheng Yang, Ray Lee Lin, “Transformerless high step-up DC-DC Converter using Cascode technique”, in International Power Electronics Conference (IPEC10), 2010.

[7] Lung Sheng Yang, Tsomg Juu Liang, Jiann fuh Chen, “Transformerless DC–DC Converters with High Step-Up Voltage Gain”, in IEEE Transactions on Industrial Electronics, vol.56, no.8, August, 2009.

[8] Yang L S, Liang L S, Chen J F, “Transformerless DC-DC Converter with high step-up voltage gain”, in IEEE Transaction on Industrial Electronics, vol.56, no.8, pp.3144-3152, 2009.

[9] M H Rashid, Power Electronics, 2nd Edition, Englewood Cliffs, NJ: Prentice- Hall, 1993.