POWER CONVERTERS IN RC SUBMARINE

A PROJECT REPORT

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by

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NOVEMBER 2024

CERTIFICATE

This is to certify that the project work titled ***"POWER CONVERTERS IN RC SUBMARINE"*** submitted by **AMISHA ROY, ADITYA GOYAL, DEEPVANSH SRIVASTVA** 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.

Dr. Sri Revathi B

(Project Supervisor)

The thesis is satisfactory / unsatisfactory

Internal Examiner **External Examiner**

Approved by

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ABSTRACT

This research focuses on the research, design, and simulation of power converters for an **RC Submarine Propulsion System**, with the aim of improving the efficiency and power supply. The propulsion system; proposed here, consists of two distinct sets of propellers: the front propellers, which require higher power and voltage for efficient operation, and the rear propellers, which require lower power and voltage. A Flyback Converter is selected to supply the necessary power to the front propellers, enabling voltage step-up and ensuring stable operation under varying load conditions, with a burst of voltage supply which is required for a strong propulsion. A DC-DC Boost Converter is chosen for the rear propellers, offering a compact and easy solution for voltage step-up with a stable starting process and overall stability for smooth control of direction as well as speed. The performance of both converters is analyzed through MATLAB simulations, with a focus on closed-loop control for maintaining output stability. The proposed design aims to optimize the submarine's speed and efficiency, contributing to more effective power management in underwater robotics.

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ABBREVIATIONS AND NOMENCLATURE

DC – Direct Current

AC – Alternating Current

RC – Radio-Controlled

PWM – Pulse Width Modulation

CCM – Continuous Conduction Mode

ML – Machine Learning

V_{in} – Input Voltage

V_{out} – Output Voltage

P_{out} – Output Power

I_{out} – Output Current

D – Duty Cycle

CHAPTER I

1. INTRODUCTION

1.1 INTRODUCTION

In RC submarines, efficient power management is crucial to enhance performance and operational control. The usage of DC-DC Boost Converter and Flyback Converter separately in the front and rear propellers respectively, allows to improve speed and maneuverability, tackling water resistance effectively; hence providing efficiency.

1.1.1 Motivation

The project seeks to improve energy delivery to the propellers, enabling enhanced speed control and efficient power utilization which arises due to the problems like: speed efficiency, water resistance, limited battery capacity, and control precision. This approach aims to optimize performance while offering valuable insights into power converter applications in small-scale underwater vehicles.

1.1.2 Objectives

Throughout the project we aim at:

•Exhaustive research on the propulsion system of RC Submarine and specially emphasizing on the power converters.

•Designing and proposing a new/rarely used power-flow design of RC Submarine.

•Simulating the converters of proposed design for a robust analysis and differentiation.

1.1.3 Scope of the Work

Focused on enhancing propulsion performance, the project involves developing a closed-loop control system in MATLAB to regulate power delivered to the front and rear propellers.

The results of the work aims at providing practical insights into power converter design for small-scale submerged vehicles, contributing to advancements in RC submarine technology.

1.2 ORGANIZATION OF THESIS

This thesis is structured in a manner that logically shows the development, analysis, and viability of a dual converter system for the propulsion of RC submarines. The Introduction chapter presents the scope of technology associated with power converters used in RC vehicles and explains why two converters are necessary to perform different functions in a submarine propulsion system. It also defines the limits of the research and the need for each converter envisaged in this model.

The Theoretical Analysis of Different Converter Topologies chapter concentrates on types of converters and their working principles, performance, and applications in underwater propulsion. That is where attention is given to DC-DC boost and flyback converters, with their advantages and drawbacks highlighted on acceleration and direction changing considerations.

The Design of Dual Converter Model chapter explains how both converters are put together as one system, paying attention to factors such as duty cycle estimation, component sizing, and circuit layout. Design Analysis and Demonstration of Dual Converter Model then introduces the simulation results whereby particular parameters such as voltage stability, ripple, and efficiency are assessed. This portion illustrates how the model has been put to the tests of various performance characteristics to ensure that the propulsion requirements are achievable.

In the Future Scope of Work, the thesis focuses on advancements such as a machine learning based master controller for power management, regenerative braking system for energy recovery, and miniaturization. The Conclusion is then dedicated to reiterating the key points of the findings in context and, where possible, their significance.

CHAPTER II

2. THEORETICAL ANALYSIS OF TOPOLOGIES

2.1 EXISTING TECHNOLOGY POWERFLOW

In the existing topologies/technologies, predominantly the DC-DC Boost converter is used to drive the propulsion motors of the RC Submarine; due to the simple and convention design.

Talking about the propulsion system; Its power flow is a simple chain of energy transfer from the power source (DC BATTERY) to the conventional boost converter(s) which after stepping up the voltage passes it on to the propellers/motor drives. The high output voltage is distributed uniformly to each motor, enabling them to operate effectively under a similar power supply.

This configuration simplifies the power distribution system, as only one/one type of converter is needed to handle the power requirements for multiple motors.

2.2. POTENTIAL DRAWBACKS IN EXISITING TECH

2.2.1 Lack of Electrical Isolation Between Input and Output:

The conventional DC-DC Boost converter offers no technology or method for electrical isolation between the input and output of the machinery.

This lack of isolation implies no protection against potential faults or voltage spikes from the motors that could propagate back into the power supply. Issues like this can easily lead to damage of the battery or other sensitive components, reducing system reliability and lifespan. Additionally, the absence of isolation makes it more difficult to implement safety features such as short-circuit protection or fault tolerance without adding complexity to the design.

2.2.2 Limited Control Over Multiple Operating Modes:

RC submarines require different operational modes, such as speed bursts, stable propulsion, and maneuvering in tight spaces. So, while the conventional boost converter offers a great step-up in voltage but fails to efficiently meet these tailored needs of different operation mode. Therefore, it becomes challenging to achieve optimal performance in different conditions which prevail under water making deep sea exploration a great challenge.

Further, this limitation can result in inefficient power use, where the same power settings are applied regardless of the specific need, reducing overall operational efficiency and responsiveness.

2.2.3 Inefficient control over the maneuvering:

In submarines it is crucial to have a through differentiation between the propellers along with a different control strategy of the usage of both for efficient use of power. The use of conventional topology reduces the scope of separate control over the propellers/DC Drive leading to a reduced specialized operation; such as deep-sea direction maneuvering. This problem may arise due to the following of the factors:

•Lack of differentiation between the propellers and their functionality due to compact and simple design.

•All propellers powered by same converter leading to a disturbance in one due to change in demand of another.

•Similar kind of input to every propeller leading to no variation of speed operation.

While the single DC-DC Boost converter topology in RC submarines provides a simple and cost-effective solution, it is limited in terms of flexibility, reliability, and control. The lack of electrical isolation, insufficient power management, and the inability to independently control multiple motors under different operational modes are key drawbacks that affect the overall performance and efficiency of the system.

2.3 PROPOSAL OF NEW DESIGN (MULTICONVERTER DESIGN)

Keeping in mind the challenges faced by the technology of RC Submarine due to the dependency on only conventional boost converter we propose a model which incorporates usage of two different converters and which comes with a properly differentiated and task specific design.

The model is equipped with two converters: Flyback Converter and DC-DC Boost converter(conventional) to supply power to the propellers; with each converter sufficing the need of a particular set of motor drive/propellers.

Hence, this model aims at tackling the challenges faced by the existing topologies.

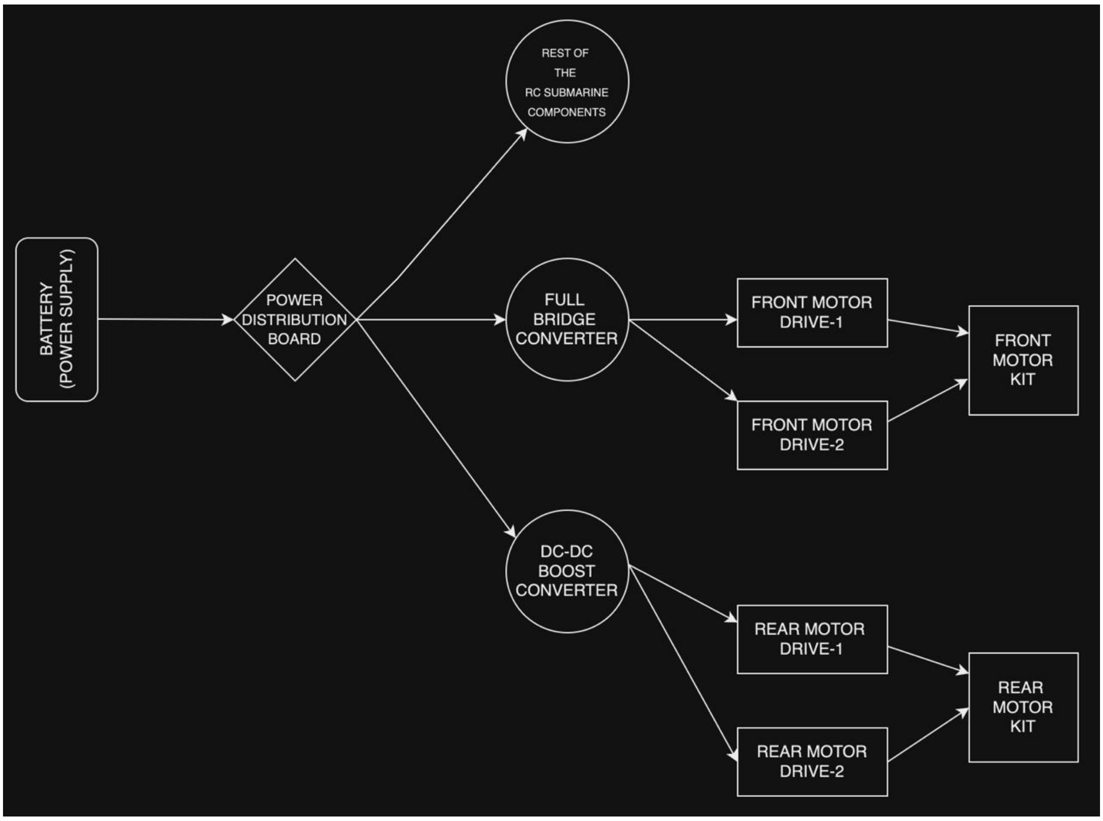


Figure 1: Power Flow Diagram of Dual Converter Design

2.4 THEORY OF DUAL CONVERTER DESIGN

Further in our study, we propose a novel propulsion system for RC Submarines which leverages the advantages of distinct power conversion topologies and benefits of electrical efficiency.

2.4.1 FRONT PROPELLER – FLYBACK CONVERTER:

The front propeller will be controlled by a Flyback converter, which is chosen because of its ability to handle high voltage overshoot at the beginning of operation.

This characteristic of flyback converter helps in generating speed bursts which is required for quick acceleration to maneuver quickly, overcome water resistance and sudden movements under water.

The flyback converter has very low ripples during the steady state operation and it helps in a smooth and stable control of motor for normal operation.

Hence the flyback converter is an overall good choice as: maintains a stable and consistent motor speed over extended periods, minimizes energy losses and provides electrical insulation for protection.

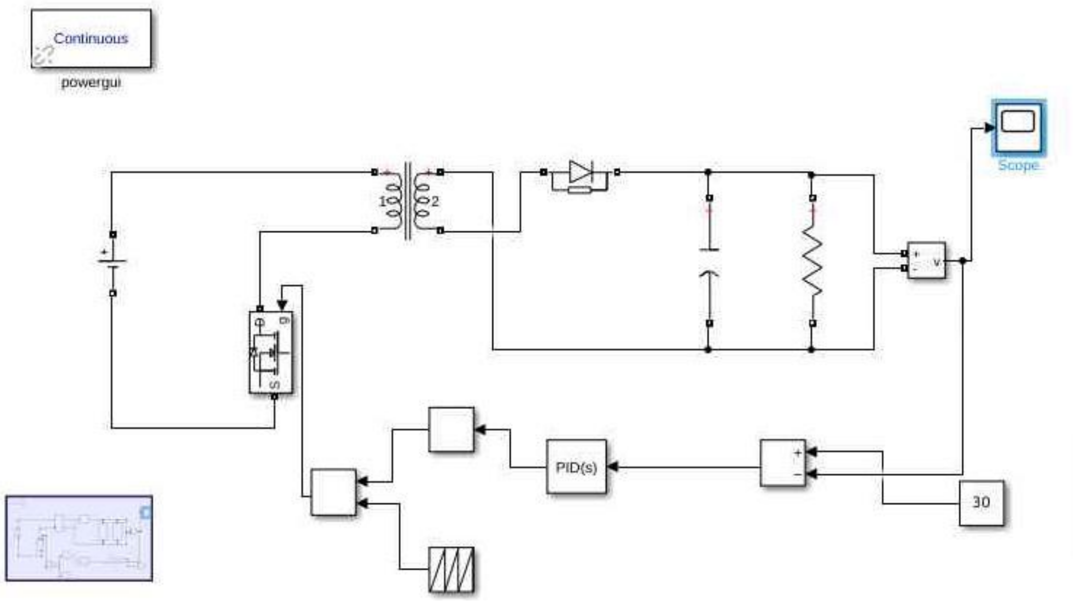


Figure 2: Circuit Diagram for Flyback Converter

2.4.2 REAR PROPELLER – CONVENTIONAL DC-DC BOOST CONVERTER:

In contrast, the rear propeller will be powered by a conventional DC-DC Boost converter. The Boost converter provides a steady, smooth output voltage, making it well-suited for continuous propulsion applications that require a consistent speed over time. Unlike the Flyback converter, the Boost converter does not experience significant voltage overshoot at startup and operates more linearly, making it ideal for steady-state power delivery.

This feature is particularly beneficial for the rear propeller, where the propulsion system is required to maintain a constant, controlled speed for regular movement and stability during normal as well as rapid cruising conditions.

Hence, this design ensures a distribution of workload and transfer of energy to the propulsion system in a more specified manner, helping in efficient control of the vehicle in all operating speeds and conditions.

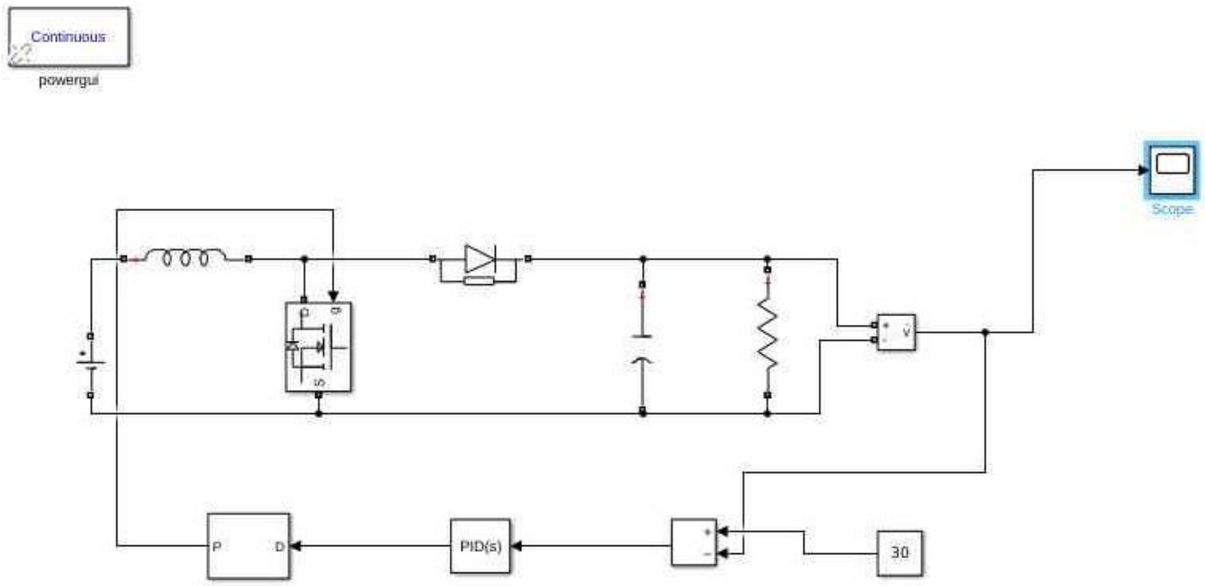


Figure 3: Circuit Diagram for CONVENTIONAL DC-DC BOOST CONVERTER:

CHAPTER III

3. DESIGN OF MULTI-CONVERTER MODEL

3.1 DESIGN APPROACH

Further, to validate the study of the new model we take help of MATLAB simulation for building a preliminary basis of the theory, by designing circuits and analyzing their output voltage waveforms.
With the help of circuit simulation, we can prove the ability of the converters to help in the propulsion system of the RC Submarine, by analyzing the overshoot voltage, steady state stability, ripples, and regulation of output voltage.

3.2 DESIGN CALCULATIONS

To design the converters, we take into consideration some basic assumptions of the parameters which would help in obtaining the components value of the power converters.
The given/assumed parameters are:

Input Voltage= 12V
Output Voltage=30V
Frequency= 50KHz
Output Power= 75W

These above stated parameters are taken into calculations on the basis of the requirements of the RC Vehicle which we are working to develop.

3.2.1 Flyback Converter Design

Duty cycle ; $D = \frac{V_{out} + V_d}{V_{out} + V_d + V_{in}} \approx 0.719$

where, $V_d = 0.7V$

Turn's Ratio ; $n = \frac{V_{out} + V_d}{V_{in}(1-D)} \approx 9.1$

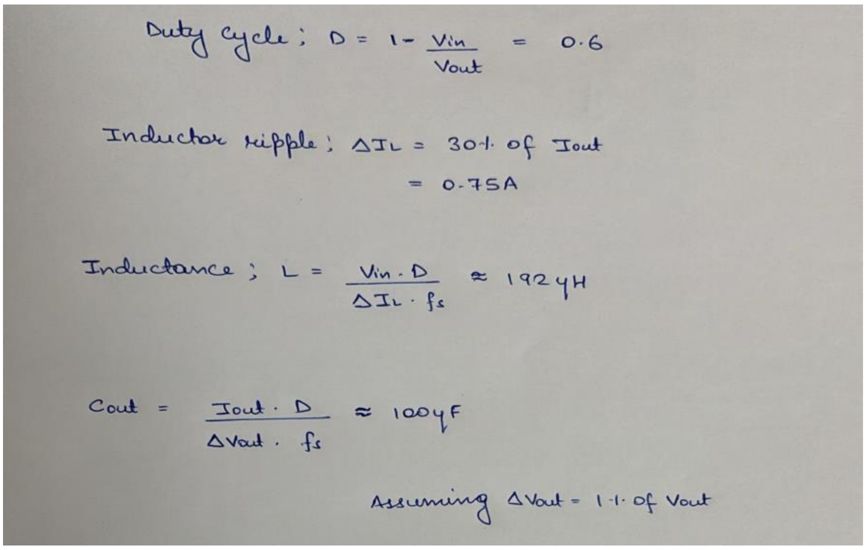
$= \underline{9.1 : 1}$

Primary Inductance ; $L_p \geq \frac{V_{in} \cdot D \cdot (1-D)}{I_{out} \cdot f_s}$

$\Rightarrow L_p \geq 19.4\,\mu H$

$C_{out} = \frac{I_{out} \cdot D}{f_s \cdot \Delta V_{out}} \approx 119.8\,\mu F$

3.2.2 DC-DC Boost Converter Design



Duty cycle ; $D = 1 - \frac{V_{in}}{V_{out}} = 0.6$

Inductor ripple ; $\Delta I_L = 30\%$ of I_{out}

$= 0.75A$

Inductance ; $L = \frac{V_{in} \cdot D}{\Delta I_L \cdot f_s} \approx 192 \mu H$

$C_{out} = \frac{I_{out} \cdot D}{\Delta V_{out} \cdot f_s} \approx 100 \mu F$

Assuming $\Delta V_{out} = 1\%$ of V_{out}

3.3 DESIGN SPECIFICATIONS

PARAMETER	VALUE
Input Voltage	12 V
Output Voltage	30 V
Output Power	75 W
Output Current	2.5 A
Switching Frequency	50 kHz
Duty Cycle	0.6
Inductance	192 uH
Output Capacitance	100 uF
Load Resistance	12 ohm

TABLE 1: Design Specs of DC DC Boost Converter

PARAMETER	VALUE
Input Voltage	12 V
Output Voltage	30 V
Output Power	75 W
Output Current	2.5 A
Switching Frequency	50 kHz
Duty Cycle	0.719
Primary Inductance	19.4 uH
Output Capacitance	120 uF
Turns Ratio	9.1:1
Diode Forward Voltage	0.7 V
Load Resistance	12 ohm

TABLE 2: Design Specs of Flyback Converter

CHAPTER IV

4. DESIGN ANALYSIS AND DEMONSTRATION

4.1 INTRODUCTION

By the end of our study and simulation we are finally at a level to analyze and validate our theory for verification.

The MATLAB simulation provided us the results about the output voltage by both the converters used(appendix) and with the help of achieved results we analyze our study by:

•Differentiation table for performance of converters

•Observation of graphs for evaluating stability, ripples at stable state, voltage overshoot and settling time.

4.2 SIMULATION RESULTS

The Autonomous Slot-car system will consist of a special car, sensors on the track and computer control software. It will provide a range of features to enhance the single player experience of a Scalextric product. It will be able to race competitively against the customer at various difficulty levels.

4.2.1 SIMULATION RESULTS OF FLYBACK CONVERTER

The flyback converter was simulated with an input voltage of 12V and a target output of 30V. The output voltage waveform was analyzed in both zoomed-in and zoomed-out views to understand its transient and steady-state characteristics fully.

- ❖ Initial Voltage Surge: At the start, the flyback converter exhibits an initial voltage spike, temporarily exceeding the target of 30V. This brief surge is due to the converter’s inherent response characteristics, where stored magnetic energy in the transformer is released rapidly at startup. This surge can be beneficial for the front propellers, providing an immediate acceleration boost necessary for quick speed adjustments.

- ❖ Ripple Voltage: In the steady-state zoomed-in waveform, the flyback converter displays a relatively low ripple, approximately ±0.05V around the target output. This low ripple reflects the flyback's ability to maintain smooth output voltage, which is advantageous in applications where stable power is desired. The minimal ripple ensures that the output remains consistent, suitable for maintaining the desired speed with minimal fluctuations.
- ❖ Settling Time and Overshoot: The flyback converter reaches near-steady output quickly after the initial surge, with a settling time under 0.5 seconds. Overshoot is minimal, as the converter stabilizes smoothly at the desired 30V. This controlled behavior provides dynamic responsiveness to the front propellers, helping achieve the intended propulsion acceleration with minimal delays or voltage spikes.

4.2.2 SIMULATION RESULTS OF DC DC BOOST CONVERTER

The DC-DC boost converter, also simulated with a 12V input and a target output of 30V, was similarly analyzed under both zoomed-in and zoomed-out views.

- ❖ Ripple Voltage: The output waveform of the boost converter demonstrates a peak-to-peak ripple of approximately ±0.1V to ±0.15V around 30V. This ripple is slightly higher than the flyback converter but can be reduced with additional output filtering, such as capacitive or LC filters. With filtering, the boost converter's ripple can be minimized to provide the stability required for precise directional control at the rear propellers.
- ❖ Settling Time and Stability: The zoomed-out view shows that the boost converter reaches the target output voltage quickly, with a similar settling time to the flyback converter, under 0.5 seconds. Once stable, the output voltage remains close to the desired 30V with minimal fluctuations, achieving reliable performance for applications where steady output is essential. This stability is well-suited for rear propeller applications, where consistent thrust enables accurate maneuvering and directional control.
- ❖ Suitability for Rear Propellers: While the ripple is slightly higher than in the flyback, the boost converter's steady output, once filtered, makes it ideal for applications requiring precision. The rear propellers, responsible for direction

and control, benefit from this predictable, stable power output, facilitating controlled movements without unintended fluctuations.

4.3 ANALYTICAL RESULTS

The flyback and boost converters each exhibit unique characteristics that make them suited to different roles in the RC submarine's propulsion system. The flyback converter, with its initial voltage surge and low ripple, is optimized for applications requiring rapid acceleration and dynamic speed adjustments, making it ideal for the front propellers. In contrast, the boost converter, with additional filtering to reduce ripple, provides a steady, stable output suitable for applications needing precision control, making it appropriate for the rear propellers.

The following table summarizes the performance characteristics of each converter based on key metrics, illustrating their suitability for their respective roles in the submarine propulsion system:

PARAMETER	**FLYBACK CONVERTER (Front Propellers)**	**BOOST CONVERTER (Rear Propellers)**
I/p voltage	12V	12V
Target o/p voltage	30V	30V
Initial surge	Yes, provides a temporary boost	No significant surge
Ripple voltage	±0.05V	±0.01 to ±0.15V (can be reduced with filtering)
Settling time	< 0.5seconds	< 0.5 seconds
Overshoot	Minimal	Minimal
Stability	Very stable with low ripple	Stable with slightly higher ripple
Ideal Application	Acceleration & speed control	Directional control & maneuvering

TABLE 3: Parameter Differentiation

CHAPTER V

5. FUTURE SCOPE OF WORK

The current design of the RC submarine propulsion system establishes an efficient and purpose-driven use of power converters tailored to different propulsion roles. This approach can be further enhanced by exploring several key advancements that improve operational flexibility, energy efficiency, and overall control intelligence. As we look toward potential developments, it's clear that integrating adaptive, data-driven control systems and enhancing component design could yield substantial benefits. The following sections outline these promising directions.

DEVELOPMENT OF A MACHINE LEARNING-BASED MASTER CONTROLLER FOR COORDINATED CONVERTER OPERATION

A significant future enhancement for this system involves the integration of a machine learning (ML)-based master controller that governs the operation of both the boost and flyback converters. Currently, each converter operates independently, fulfilling its role in either acceleration or maneuverability. However, in a dynamic underwater environment, a centralized control system could vastly improve coordination and responsiveness. An ML-based controller could learn optimal operating patterns and dynamically adjust the converters based on real-time conditions such as depth, battery status, speed, and external disturbances.

The master controller would function as a data-driven optimizer, adapting converter parameters (e.g., duty cycle, switching frequency) in response to the submarine's current and predicted power demands. by utilizing historical operational data and real-time sensor inputs, the ml controller could make informed decisions, such as prioritizing power to the front propellers when acceleration is required or shifting focus to the rear propellers for precise directional control. such adaptability would lead to improved energy efficiency, reduced wear on components, and enhanced mission duration for extended underwater operations. additionally, the controller could be designed to incorporate a fault-detection mechanism, using anomaly detection algorithms to identify and address potential issues with the converters before they impact performance.

ENHANCED ENERGY MANAGEMENT WITH REGENERATIVE POWER RECOVERY

Another promising area for future work is implementing regenerative power recovery within the propulsion system, which would allow the submarine to conserve energy during deceleration and idle phases. In particular, the system could capture energy from the rear propellers as they slow down during maneuvering or come to a stop, then store this recovered energy for subsequent use. This approach is common in electric vehicles and can be adapted here to extend battery life—a crucial factor for autonomous RC submarines operating remotely or for long durations.

Integrating regenerative power capabilities would involve modifying the converter circuitry to allow bidirectional power flow, which could be achieved through intelligent control circuitry that temporarily switches the converters into regenerative mode when appropriate. Combined with the ML-based master controller, this feature could enable the controller to assess when regeneration is most feasible and efficient, thus managing power flow intelligently to maximize operational time and optimize energy usage.

SOFT-START MECHANISMS FOR ENHANCED COMPONENT PROTECTION

The initial voltage surge observed in the flyback converter at startup, while beneficial for quick acceleration, may place additional stress on both the converter components and the front propellers. To mitigate this, future designs could incorporate soft-start mechanisms to gradually ramp up voltage upon initialization. By controlling the rate of voltage increase, these soft-start circuits would help limit inrush current, reducing the risk of overheating and mechanical stress on sensitive components.

A gradual startup process would also help prevent unexpected power spikes, allowing for smoother transitions and extending the lifespan of critical parts. This feature would be particularly beneficial for applications requiring repetitive starts and stops or for submarines operating in environments where gentle power handling is required to avoid disturbing surrounding ecosystems. Implementing soft-start mechanisms can thus contribute to the reliability and longevity of the propulsion system, especially when combined with a master controller that could determine the optimal startup rate based on real-time data.

MINIATURIZATION AND INTEGRATION OF HIGH-FREQUENCY COMPONENTS FOR ENHANCED COMPACTNESS

Lastly, miniaturization of the converter components through the use of high-frequency designs and advanced materials holds significant potential. Transitioning to a higher switching frequency than the current 50 kHz would allow for smaller inductors and capacitors, reducing the size and weight of the power converters. However, increasing frequency also demands careful attention to efficiency and heat dissipation.

Future designs could incorporate wide-bandgap semiconductor materials such as gallium nitride (GaN) or silicon carbide (SiC), known for their ability to operate efficiently at higher frequencies and handle high power with minimal heat loss. By leveraging these advanced materials, the converters could be made smaller and more efficient, freeing up space within the submarine for additional sensors or other payloads. The reduced weight and size would also contribute to improved maneuverability and reduced energy consumption, making the submarine more agile and responsive to control commands.

CHAPTER VI

6. CONCLUSION

To summarize, this paper proposes a dual- converter propulsion system that is unique to the operational characteristics of the RC submarines, featuring a Flyback converter that aids with safe bursts of speed for acceleration and Boost converter assisting in smooth and controlled movement. By minimizing the constraints associated with the use of single converters systems, the proposed systems provide great flexibility, operational handling and energy management which are highly required for operational under the sea environments. Such detailed analysis, calculations and design considerations form a strong basis for this model which seeks to deliver optimum power with minimum electrical losses while ensuring the stability of the output.

This work also expands the possibilities for further development: the introduction of an AI-based master controller and the investigation of new advanced converter topologies such as multi-phase or the bidirectional converter.

To sum up, this report provides great primary material for the development of novel energy efficient propulsion systems for small size RC submarines and possible applications for autonomous underwater vehicles.

CHAPTER VII

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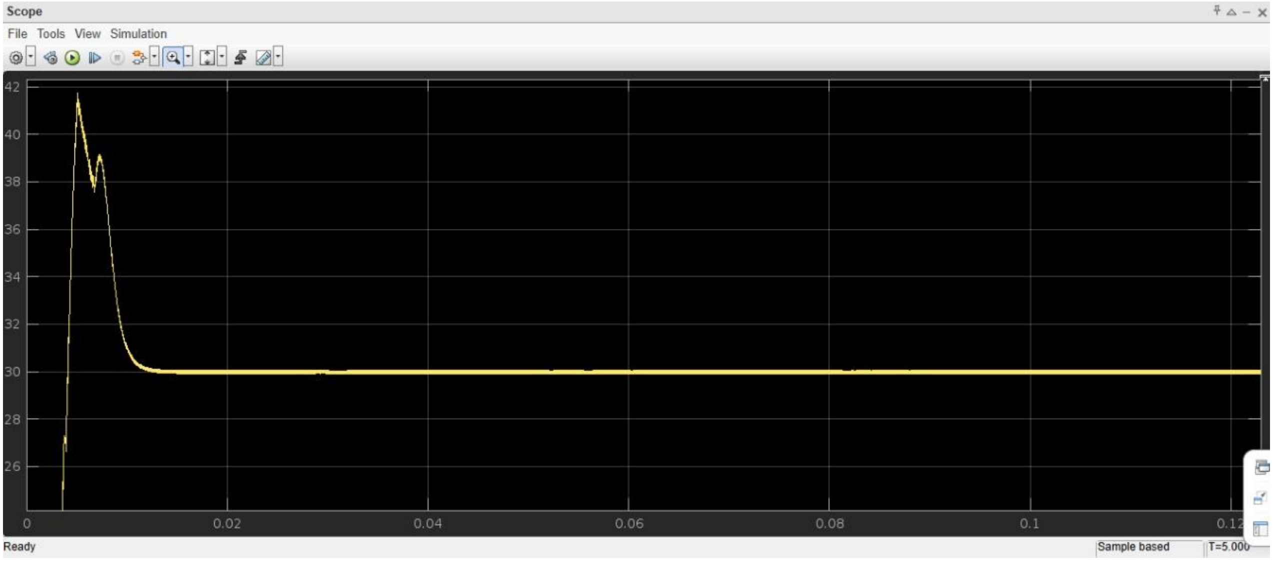
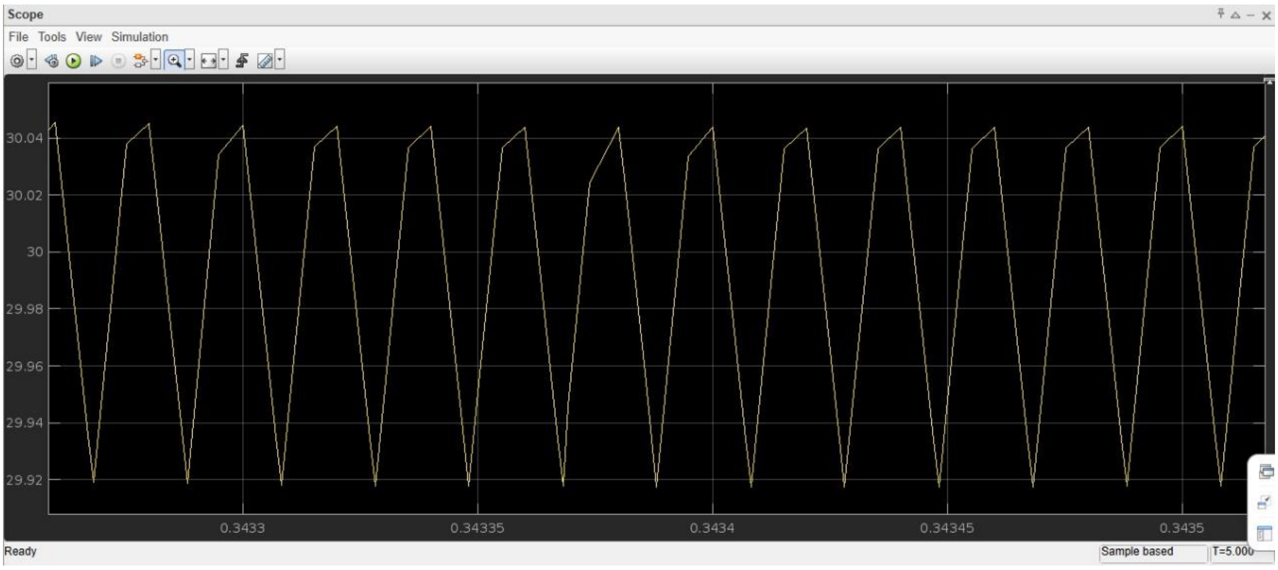
APPENDICES

Appendix 1: Output Voltage of Flyback Converter

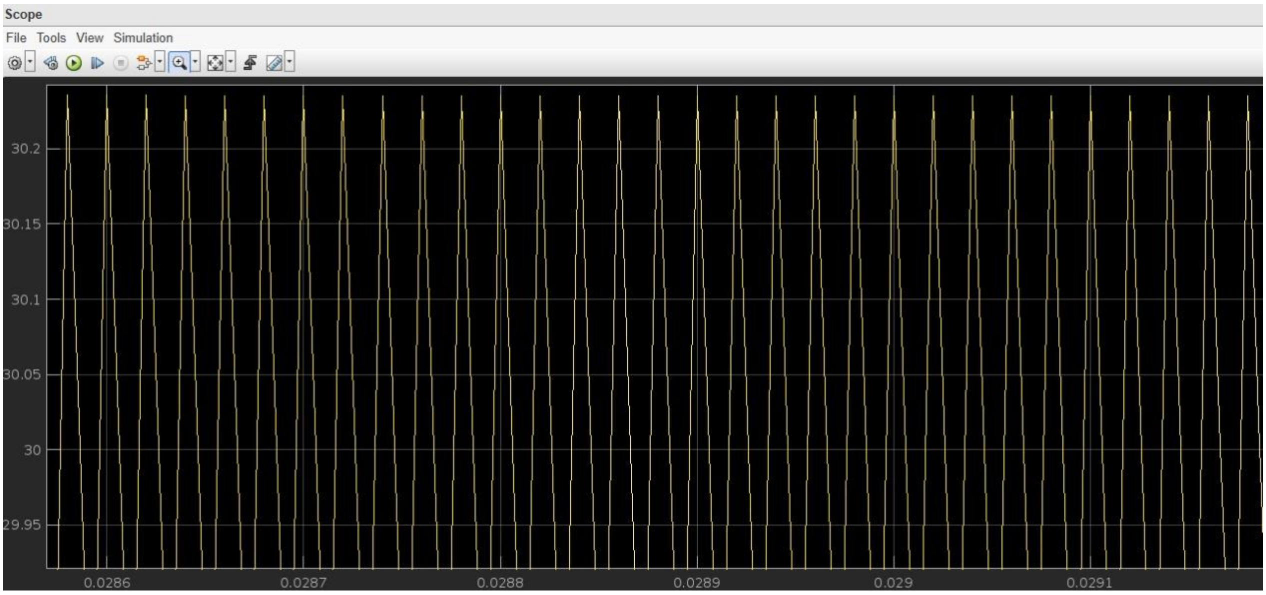


Appendix 2: Ripple view of output voltage for Flyback Converter



Appendix 3: Output Voltage of DC DC Boost Converter

Appendix 4: Ripple view of output voltage for DC DC Boost Converter



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