A Project Report

On

# Composite nonlinear feedback control of a DC-DC boost converter under input voltage and load variation

BY


GROUP NUMBER 6

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# ABSTRACT

This paper presents a comprehensive investigation into the application of composite nonlinear feedback (CNF) control for enhancing the voltage regulation of a DC-DC boost converter in DC microgrids. The study introduces a novel tuning algorithm for the composite nonlinear feedback (CNF) controller, addressing the challenges posed by input voltage fluctuations and load variations. Experimental validation of the proposed control strategy demonstrates its effectiveness in achieving rapid convergence to setpoints and improved transient performance. Comparative analyses with traditional linear controllers, such as model predictive control (MPC), highlight the superior performance of the CNF approach. The findings of this research offer valuable insights into the potential applications of CNF control in enhancing the stability and efficiency of DC microgrid systems, particularly in the context of intermittent energy sources.

# CONTENTS



## 1. INTRODUCTION

The project report focuses on the implementation and analysis of a composite nonlinear feedback (CNF) control system for a DC-DC boost converter, as detailed in the research article "Composite Nonlinear Feedback Control of DC-DC Boost Converters" by A. Vazani et al. The CNF approach offers a promising solution for enhancing the performance of boost converters in DC microgrids, particularly in managing variable input voltages and changing loads. This report aims to investigate the effectiveness of the CNF controller through simulation and experimental validation, highlighting its advantages over traditional control techniques such as model predictive control (MPC). By delving into the theoretical framework and practical applications of CNF control, this project seeks to contribute to the advancement of control strategies for renewable energy systems.

## 2. METHODOLOGY

### DC-DC Boost Converter:

The DC-DC boost converter is a power electronics circuit that takes an input DC voltage (Vin) and produces an output DC voltage (Vout) that is higher than the input voltage. It is useful for applications that require a higher voltage level than what is provided by the DC source, such as solar panels or fuel cells.

The basic topology of the boost converter consists of:

- An inductor (L)
- A diode (D)
- A power switch (typically a MOSFET or IGBT)
- An output capacitor (C)
- A load resistance (R)

The input voltage source provides energy to the inductor when the power switch is closed (ON state), which causes the inductor current to rise and stores energy in its magnetic field. The output stage is isolated throughout this period of reverse-biasing of the diode.

When the switch is opened (OFF state), the energy stored in the inductor tries to maintain current flow. This forward-biases the diode, allowing the inductor current to flow through the diode, charging the output capacitor and supplying the load. The output voltage (Vout) is higher than the input voltage (Vin) due to this inductive energy transfer process.

The ratio of the output and input voltages is controlled by adjusting the duty cycle (d) of the switching waveform applied to the power switch. A higher duty cycle results in a higher output voltage.

The key equations governing the steady-state behaviour are:

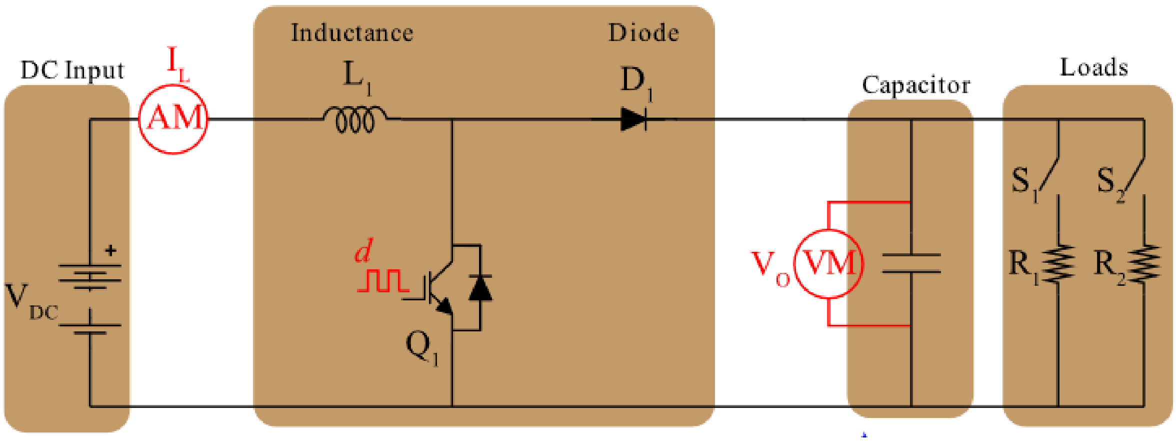
$Vout = Vin / (1 - d)$

$Iout = d * Iin$

Where Iin and Iout are the input and output currents respectively.

The inductor (L) and capacitor (C) components act as filters to provide a smooth DC output voltage and current, minimizing ripple. In the paper, a control strategy using composite nonlinear feedback

(CNF) is proposed to regulate the output voltage against input voltage variations and load changes, while improving the transient response by reducing overshoot.




Architecture

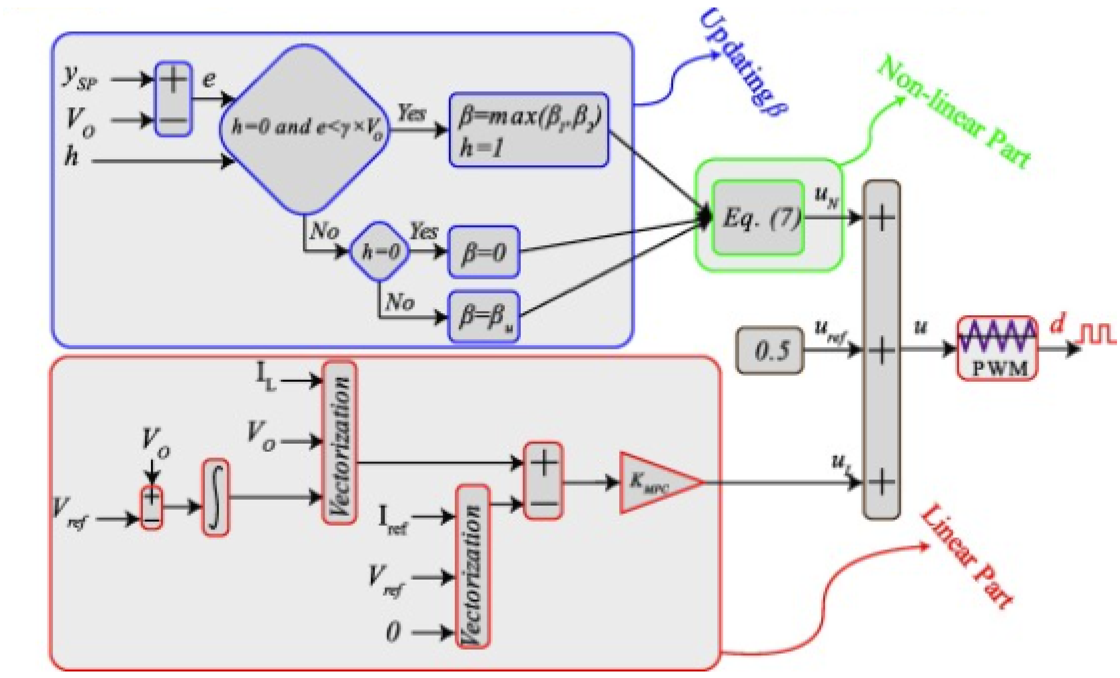
- This converter has a direct current input that receives power from DC sources such as solar panels, and fuel cells
- Three main elements of an inductor, a diode, and a power switch are used to increase the input voltage in this system.
- A capacitor is connected to the boost converter's output, which helps to stabilize and minimize the ripples in the output voltage.
- Finally, a load in form of controllable resistors is connected to an output capacitor.

$$L.\frac{dI_L}{dt} = V_{DC} - V_o(1-d)$$

$$C.\frac{dV_o}{dt} = I_L(1-d) - \frac{V_o}{R}$$

where d is the duty cycle of the power switch

**Composite Nonlinear Feedback(CNF)**




The paper introduces a Composite Nonlinear Feedback (CNF) control strategy for enhancing the transient performance of a DC-DC boost converter system. The methodology is divided into several sections.

**1. System Modeling:**

The system is initially described by nominal linear equations with state vector $x$, constrained control input $u$, and measured output $y$. Actuator saturation effects are accounted for, defined by saturation levels $u_{\max}$ and $u_{\min}$. The CNF controller is designed assuming system stabilizability, detectability, and invertibility, aiming to track a reference signal $r$ quickly without significant overshoot or adverse effects from saturation.

**2. Controller Design:**

Equilibrium points of the system are calculated to understand its behavior. The control signal $u$ drives the output to track a constant reference $r$. The linear control feedback is designed using a gain matrix $K$ derived from optimization methods like LQR or LMI-based minimization, ensuring stability within saturation limits. A nonlinear feedback law is introduced to enhance damping ratio and minimize overshoot. The nonlinear function is chosen based on properties ensuring stability and transient performance, typically an exponential function. Parameters of the nonlinear function are tuned to optimize performance.

**3. CNF Controller Gain Tuning:**

Two stages go into fine-tuning controller parameters. Initially, a quadratic performance index is used to improve linear feedback gains. The nonlinear function's parameters are changed in the following stage. The objective is to keep saturation levels and stability while minimizing a performance index. For stability and ideal parameter tweaking, a theorem and lemma are given.

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**4. Stability Analysis:**

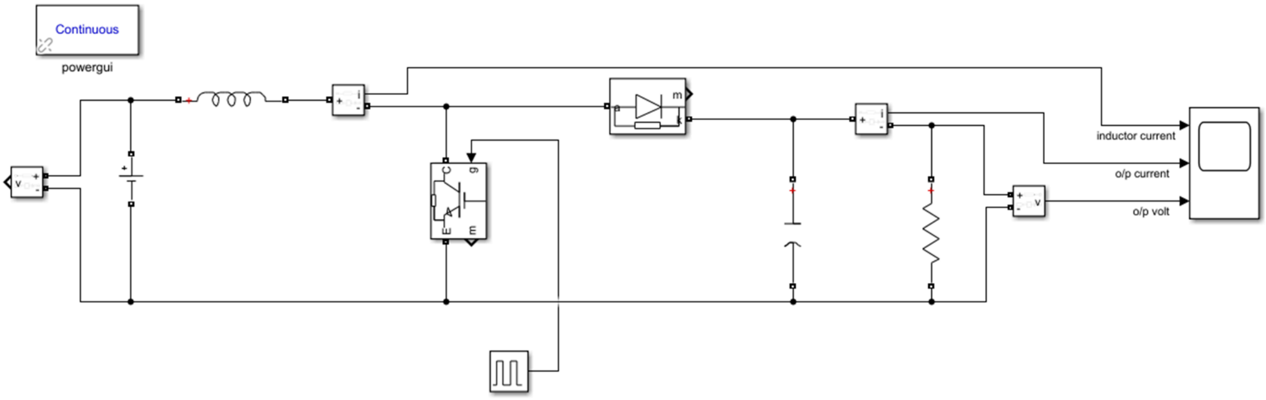
Lyapunov stability theory and eigenvalue analysis are used to perform stability analyses. Mathematical arguments demonstrate that the closed-loop system is asymptotically stable with proper parameter tuning. Eigenvalue analysis confirms stability and provides information about transitory behavior.

**5. Simulation and Evaluation:**

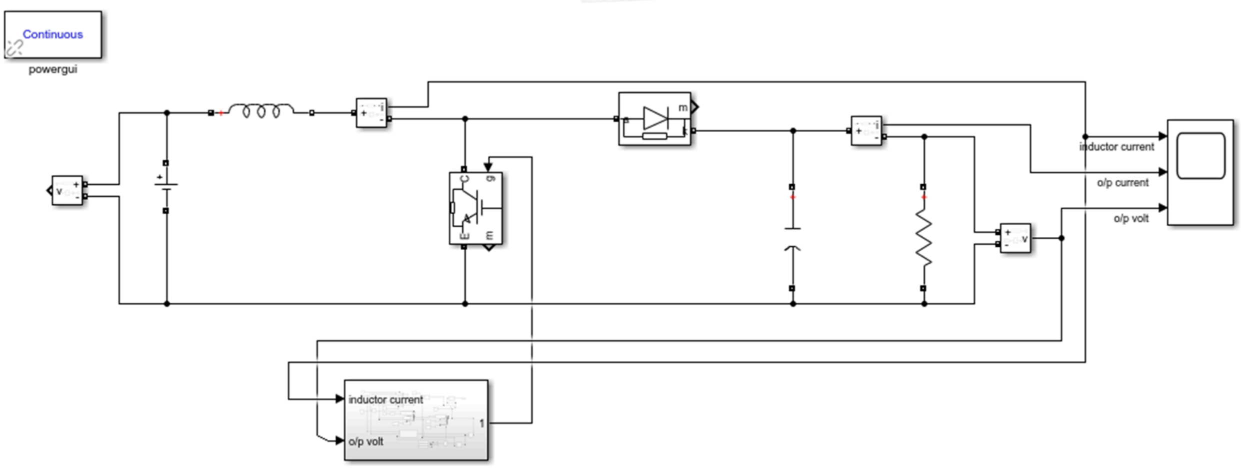
The suggested CNF controller is assessed using MATLAB Simulink simulations. Several operational situations are investigated, including input voltage fluctuations, reference voltage changes, load shifts, and parameter uncertainty. The simulation findings show that the CNF controller outperforms the Model Predictive Control (MPC) technique. Even in the presence of uncertainties, the CNF controller responds faster, with less overshoot and smoother transitions.

In summary, the methodology consists of systematic modeling, design, tuning, stability analysis, and simulation assessment of the CNF controller for a DC-DC boost converter system. The approach combines theoretical analysis and practical simulations to demonstrate the CNF controller's effectiveness and robustness in increasing transient performance and minimizing the consequences of actuator saturation.

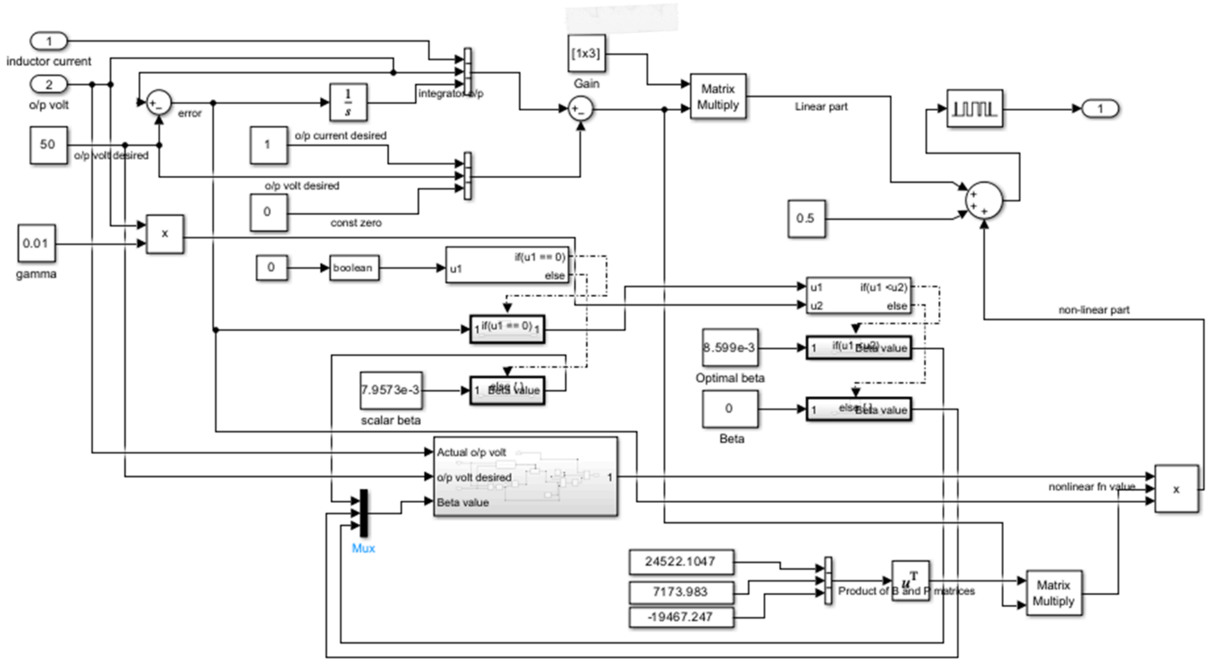
## 3. SIMULATION



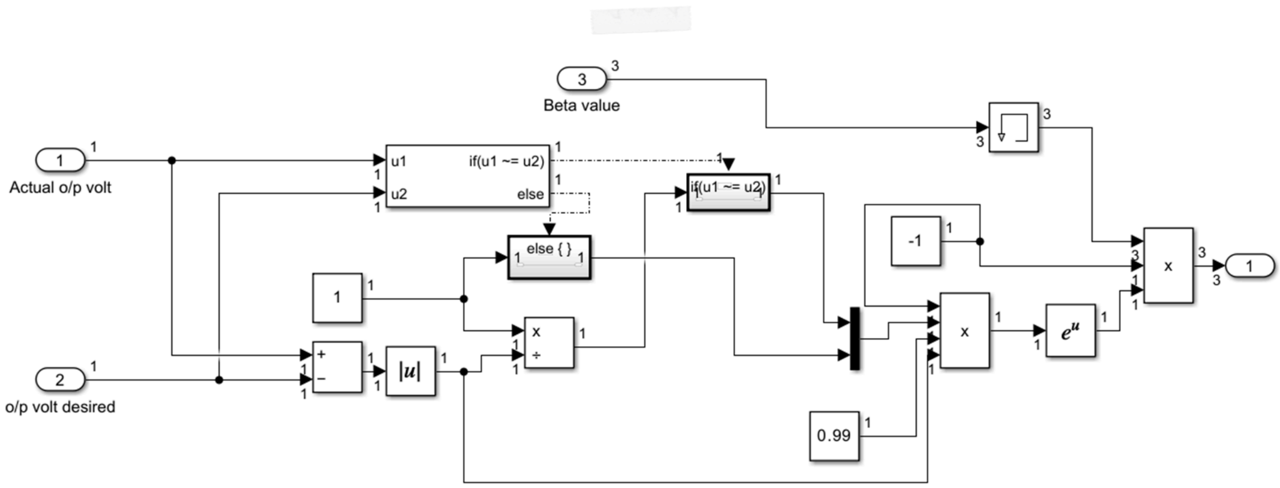

*MATLAB Simulink model of the DC-DC boost converter (with Pulse Gen, w/o CNF)*




*MATLAB Simulink model of the DC-DC boost converter (with CNF)*



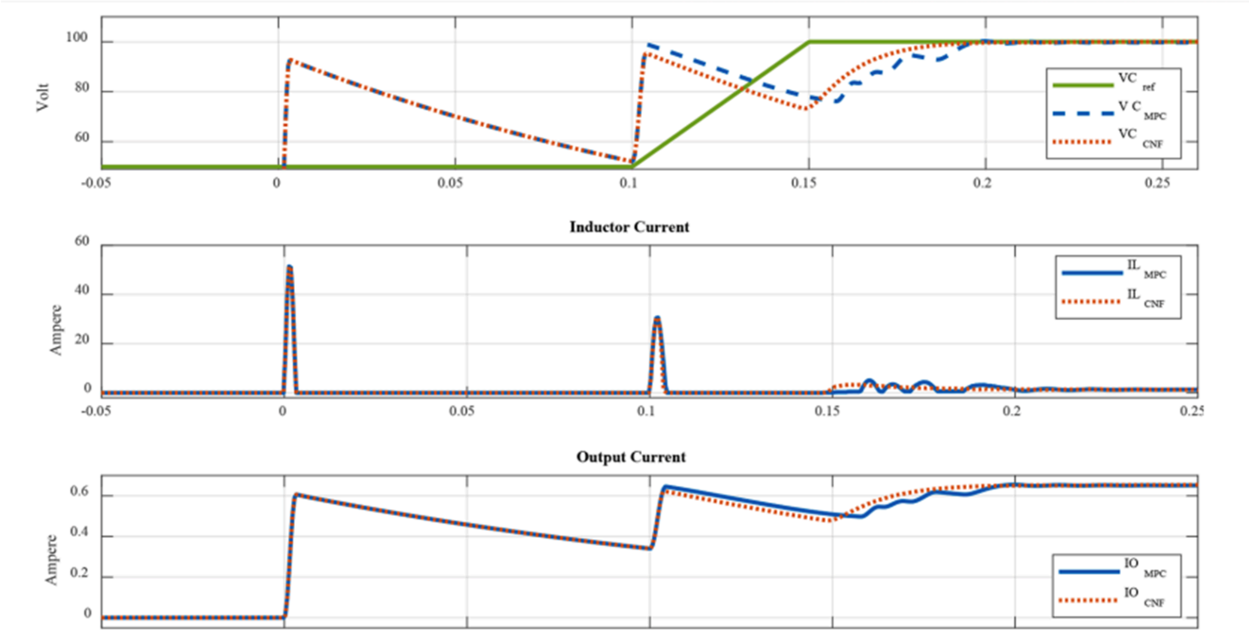

*MATLAB Simulink model of the CNF controller*



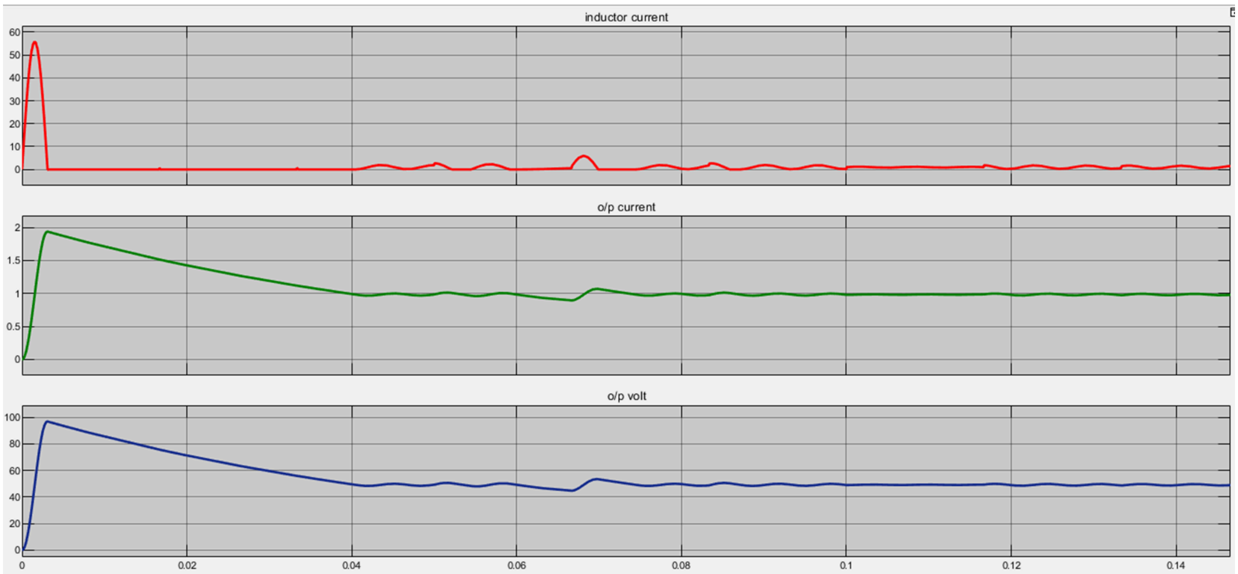

*MATLAB Simulink model of the Non-linear f/b part of the CNF*

Through the use of simulations, we were able to evaluate the performance of a normal DC-DC boost converter under different operating situations with the suggested composite nonlinear control technique. The system's reaction to changes in load, reference voltage, and input voltage was assessed in the study. According to the results, the CNF controller worked better than the standard DC-DC boost converter, exhibiting faster settling times and less overshoot. Enhanced transient response and stability were proven by the CNF controller, especially when uncertainties and parameter fluctuations were present. Overall, when compared to a traditional DC-DC boost converter, the simulations demonstrated the improved performance of the CNF technique in enhancing the dynamic behaviour and robustness of the DC-DC boost converter system.

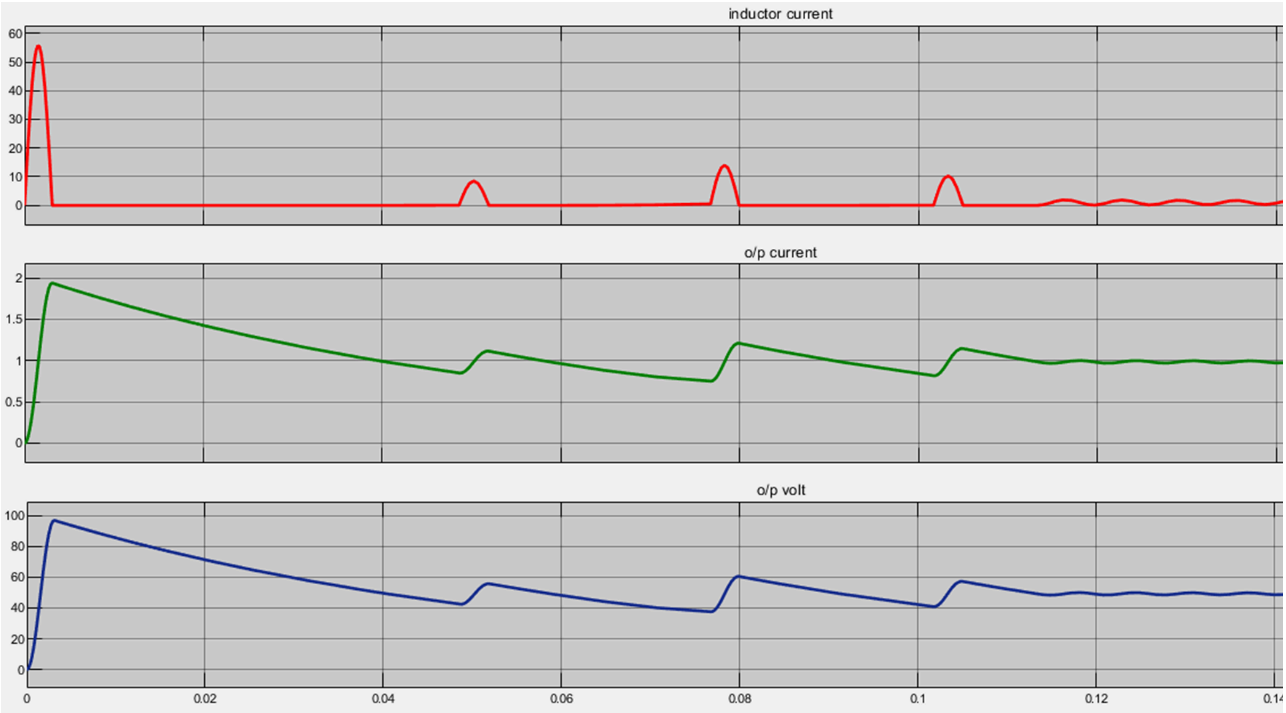
## 4. RESULTS




This waveform shown above is the output derived from the research paper for the transient response of the DC-DC boost converter with feedback control. The red



dotted line from the above waveforms is the output achieved using the CNF model and we are trying to get similar results.




The waveforms shown above are the transient response outputs of normal DC-DC boost converter with a pulse generator and the DC-DC boost converter with the CNF model simulated by us and the feedback output given to the trigger of the IGBT, respectively. We can notice that the CNF model simulated by us replicates the model as given in the research paper and has a better transient response as well as steady state response as compared to the normal DC-DC boost converter.

## 5. CONCLUSION

In order to increase transient performance and voltage regulation under input voltage uncertainties and load variations, a novel composite nonlinear feedback (CNF) control approach for a DC-DC boost converter was developed in this study. The CNF controller incorporates a nonlinear dampening component to minimise overshoot in addition to a linear feedback component that maintains stability and tracking while taking restrictions into consideration. An automated tuning algorithm that optimally modifies the nonlinear damping parameters online in accordance with the intended error bound and saturation limits is a significant innovation. Numerous scenarios involving input changes, reference steps, and load shifts were simulated extensively to show that the suggested CNF technique had a better transient response than linear control alone, resulting in less overshoot, quicker settling, and smoother transitions. Eigenvalue analysis confirmed the stability of the closed-loop system. In summary, the CNF control strategy with the novel tuning algorithm significantly enhances the dynamic performance of boost converters operating with uncertainties, making it well-suited for DC microgrids with intermittent sources and unknown loads.

## 6. REFERENCES

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