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# Modelling and Simulation Analysis and Control of Dual Active Bridge (DAB) Power Converter

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Abstract *This paper presents the lower order state-space average model of the Dual Active Bridge (DAB) power converter to eliminate the complexity in Fourier based model of transformer excitation system. The above said model has been used for designing a current control as well as multi-loop voltage control strategy for bidirectional converter. The model obtained in this paper can be directly utilized for the bi-directional converter topology utilized in the fuel cell application, electrical vehicle battery charging, solar water pumping schemes, etc., where high voltage difference voltage ports are involved. In present power applications, bidirectional converters with galvanic isolation are needed since they are light in weight and possess reasonable efficiency and rapid turnaround of the design is desirable. The reduced order model of the DAB converter is utilized in compensator design and control strategy formulation. Analytically obtained model and parameters are verified using simulations. Simulation results pertinent to the paper are given here to demonstrate the efficacy and validity of the proposed model for the DAB converter. The present work in the paper introduces the guideline of the close loop design of control of some other DAB power converter applications based on its simplified model.*

Keywords: Bidirectional power converter, Dual active bridge converter, High-frequency transformer, Phase shift control, State-space averaging.

## I.INTRODUCTION

In recent times, the wide use of electric vehicles (EV), renewable energy systems, and grid- tied energy storehouse bias has driven a huge demand for power conversion bias that are effective, dependable, and compact. Among the diversified topologies proposed to meet the demands, the dual active bridge ( DAB) motor has stood out as a prominent seeker. The DAB provides some benefits similar as galvanic insulation, high power viscosity, soft- switching eventuality, and power transfer in both directions with effective power transfer using phase- shift control.The conventional modeling of DAB transformers typically involves advanced harmonious state- space or frequence-sphere designs that require close acquaintance with switching harmonics and significant computational coffers. g g gAlthough these models offer good sapience into high- frequence dynamics, they are not doable for real- time control operations, especially those executed on digital signal processors (DSPs) or microcontrollers with limited calculation power. To circumvent this limitation, this paper suggests a lower- order state- space average model of the DAB motor. By comprising the system dynamics over half a switching period and considering only the dominant countries i.e., the motor current and affair voltage the model captures critical motor geste.

## II. LITERATURE SURVEY

The Dual Active Bridge (DAB) converter is an attractive solution for contemporary power conversion requirements because it can provide galvanic isolation, bidirectional power transfer, and high-frequency operation. It has critical applications in electric vehicles, renewable energy interfaces, and energy storage systems nventional research, such as initial works by Inoue and Akagi [12], placed great emphasis on full-order harmonic models and phase-shift modulation methods to model system behavior and provide power flow control. These models, however, tended to be difficult to implement in real time because of their computational complexity. Control strategies have also progressed. Classic Proportional-Integral (PI) control became the mode of choice because it is simple and its steady-state performance is acceptable, as in most DAB converter designs. PI control, however, tended to have poor dynamic performance when dealing with varying load and input conditions. More sophisticated strategies, like Model Predictive Control (MPC) and Sliding Mode Control (SMC), have been explored, providing quicker transients and disturbance rejection but at the expense of increased computational burden and chattering problems Contrary to this, the current work replaces the PI controller with a Proportional- Integral-Derivative (PID) controller in an innovative manner as a method of enhancing the dynamic performance of the DAB converter without causing unnecessary computational complexity. The derivative action of PID proves especially useful for enhancing transient response and minimizing overshoot, factors that are highly important in high-voltage fast-switching applications. This enhancement fills a pivotal gap in previous literature: achieving real-time controllability feasibility without compromising dynamic responsiveness. Through the use of a reduced-order state-space model as the foundation for control design, this paper not only provides computational efficiency but also enhances system flexibility. Simulation results confirm that the PID- controlled DAB converter has improved current tracking, faster settling time, and reduced steady- state error, especially in bidirectional power flow applications representing a significant advancement from PI-based approaches. In conclusion, this effort is a contribution to a widening knowledge base that seeks simple modeling with high fidelity of control, particularly for those applications in which system response time and flexibility are most critical.

## III. WORKING PRINCIPLE

The Dual Active Bridge (DAB) converter is a high- performance DC-DC converter that supports power transfer in both directions while ensuring galvanic isolation. Its design features two full-bridge converters—one at the input side and the other at the output—connected through a high-frequency transformer. This architecture makes the DAB suitable for a range of modern applications such as electric vehicle (EV) charging, renewable energy systems, and smart grid energy storage.

**Basic Operational Mechanism:**The DAB operates by generating square wave voltages from both full-bridge converters. These voltages are synchronized in frequency, but a controllable phase shift between them is introduced to regulate power flow: A positive phase shift results in energy moving from the input (high voltage side) to the output (low voltage side), known as buck mode. A negative phase shift causes power to flow in the reverse direction, referred to as boost mode. A negative phase shift causes power to flow in the reverse direction, referred to as boost mode. Here the transformer's leakage inductance comes to play a very critical role. Where there is a phase difference, it results in a voltage across the inductance which creates a ramp on the inductor current.This current represents the energy being transferred. Since the voltages on the square wave are switching at high frequency and the current is ramping, this topology is suitable for zero-voltage switching (ZVS). ZVS ensures that switches turn on and off when voltage across them is nearly zero, thereby reducing power loss and improving efficiency.

**Control Strategy:**

To ensure accurate power flow and maintain desired current or voltage levels, a closed-loop control system is necessary. Traditionally, a Proportional-Integral (PI) controller is used. This type of controller adjusts the control input (phase shift) based on the present error (difference between reference and actual output) and its accumulated history. PI controllers are relatively simple and effective in achieving zero steady-state error, but they often respond slowly to sudden changes in system conditions. In this research, we improve the control performance by substituting the PI controller with a Proportional-Integral- Derivative (PID) controller .The PID controller includes an additional derivative term that reacts to the rate of change of the error. This predictive element allows the controller to anticipate future errors and respond quicker, thus reducing overshoot, improving stability, and enabling faster recovery from disturbances. Why Use Both Controllers for Comparison? The inclusion of both PI and PID controllers allows for a direct performance comparison. The PI controller serves

as a baseline for stable, steady-state operation. Meanwhile, the PID controller enhances the dynamic performance—especially during startup, load changes, or when switching between buck and boost modes. PI Controller Observations: Simpler to implement and tune Provides accurate tracking under steady-state Slower response during fast transients or disturbances PID Controller Observations: Responds faster to load and voltage changes Reduces overshoot and settling time Handles dynamic conditions more robustly Simulated Performance Simulations carried out using MATLAB/Simulink demonstrate that the PID controller achieves tighter current control, quicker adaptation to improvements, and better transient response than the PI controller. Both controllers successfully manage bidirectional power flow, but the PID controller exhibits better control precision and dynamic robustness, making it more suitable for real-time, high-speed applications such as vehicle-to-grid (V2G) systems and dynamic battery storage units.

# MODES OF OPERATION:

- Buck Mode (Forward Mode)
- Boost Mode (Reverse Mode)

## A. *Buck Mode (Forward Mode):*

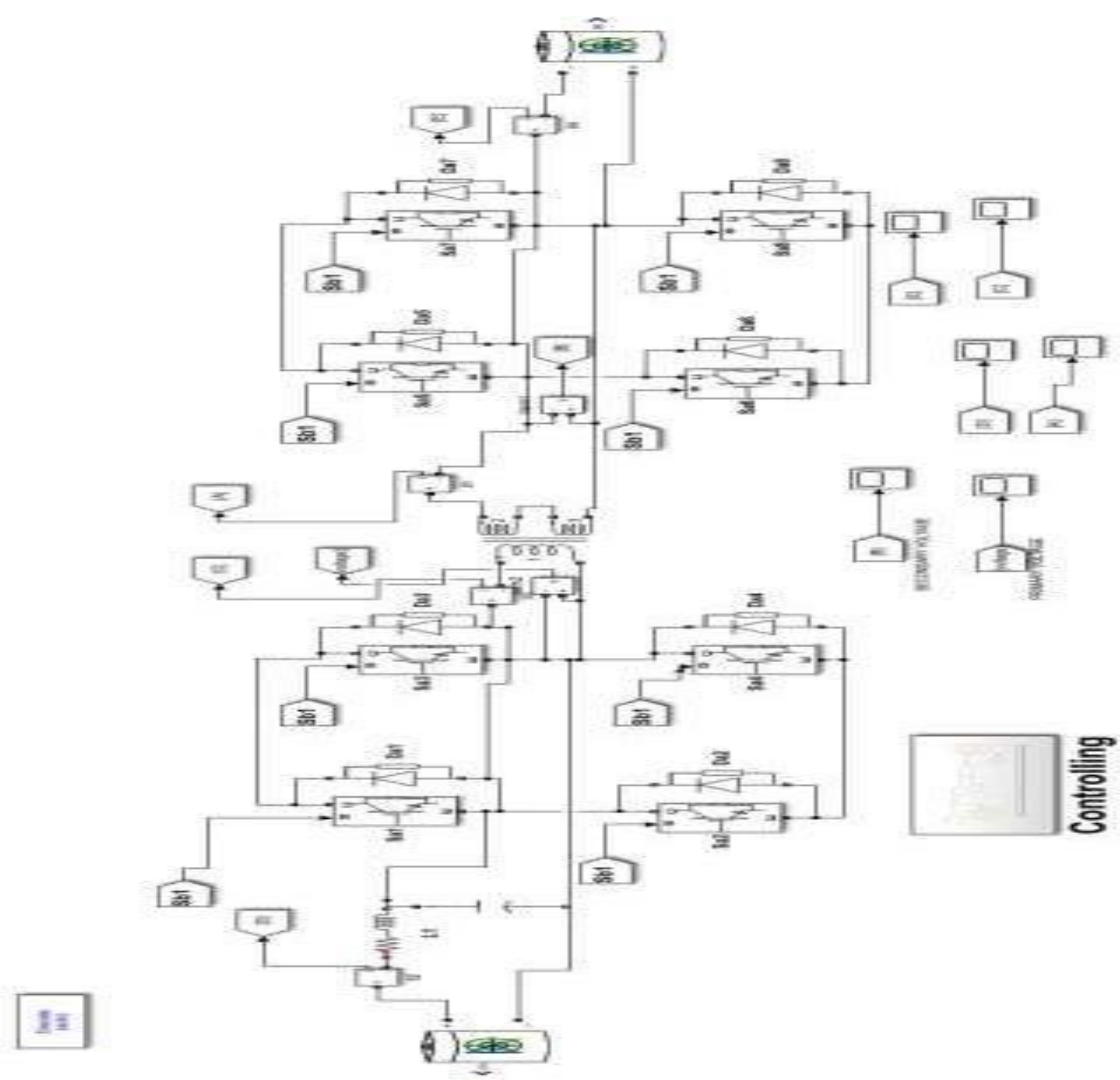
In the buck operating mode, the DAB converter facilitates power transfer from a higher voltage source such as a solar array, high-voltage DC bus, or grid interface to a lower voltage load like a battery bank or DC storage element. This mode mirrors the functionality of a conventional buck converter, where the output voltage is reduced relative to the input, but with added benefits such as galvanic isolation and bidirectional capability. This mode is initiated when the primary-side full- bridge inverter leads the secondary-side bridge in terms of switching signal phase. Specifically, a positive phase shift is introduced between the square-wave voltages generated by the two bridges. This phase difference causes a voltage differential across the leakage inductance of the high-frequency transformer, which in turn results in a linearly increasing current from the primary to the secondary side. The current waveform typically assumes a triangular shape during each switching interval due to the inductive behavior. As the current flows through the leakage inductance, energy is temporarily stored and then delivered to the output side. This energy transfer is tightly controlled by the amount of phase shift, making the system highly responsive and efficient. Importantly, this operating condition supports Zero Voltage Switching (ZVS), a soft-switching technique that allows transistors to turn on and off when the voltage across them is near zero. By timing the switching events with the natural zero- crossing of voltage or current, switching losses are significantly reduced, which not only improves efficiency but also enhances the reliability and thermal performance of the converter. This buck- mode functionality is especially advantageous in energy storage systems where a high-voltage source charges a low-voltage battery. For example, solar PV installations commonly generate high DC voltages, which must be stepped down to safely and efficiently charge battery modules. The DAB converter, operating in buck mode, provides the isolation, regulation, and efficiency needed in such applications while maintaining fast control and adaptability to load variations. Overall, the buck operation of the DAB converter exemplifies its suitability for modern power conversion systems, offering a compact and high-performance solution for controlled step-down power delivery.

## B. BOOST MODE:

In boost mode, the Dual Active Bridge (DAB) converter transfers power from the lower voltage side to the higher voltage side, enabling reverse energy flow. This mode is initiated when the secondary-side full-bridge inverter operates ahead of the primary-side inverter in terms of switching phase, resulting in a negative phase shift between their output voltage waveforms. This phase difference causes a voltage to develop across the transformer’s leakage inductance, leading to a current ramp from the secondary to the primary, effectively transferring energy back to the higher voltage terminal. The main feature of this mode is its ability to raise the voltage level at the output, making it suitable for applications where energy must be delivered from low-voltage sources—such as batteries or ultracapacitors—to high-voltage DC buses or grid-tied systems. Boost mode is commonly used in operations like discharging storage systems, vehicle-to-grid power delivery, or feeding excess stored energy back to the grid. One of the challenges in this mode is achieving Zero Voltage Switching (ZVS), especially under light load conditions. At low currents, it becomes more difficult to ensure that switches turn on at zero voltage, which can lead to increased switching losses. Therefore, precise control of the phase angle and real-time adjustment of switching parameters are necessary to maintain high efficiency. The DAB converter supports smooth transitions between buck and boost modes by merely adjusting the phase shift, without requiring hardware changes.

This ability is particularly useful in systems with frequent changes in power direction, such as electric vehicles and renewable energy installations. In such applications, the converter must adapt to both charging (buck) and discharging (boost) scenarios based on real-time demand and generation conditions. To ensure efficient performance across both modes, real-time feedback and accurate phase-shift modulation are essential.

## Schematic Block Diagram:




The diagram of the Dual Active Bridge (DAB) converter illustrates its symmetrical structure, consisting of two full-bridge inverters—one on the primary side and the other on the secondary side— connected via a high-frequency transformer. These bridges are responsible for generating square-wave voltages that are phase-shifted with respect to each other to control power flow direction and magnitude. The transformer provides galvanic isolation and helps step up or step down the voltage based on the turns ratio. The leakage inductance of the transformer acts as the main energy transfer element. A controller (PI or PID) processes the feedback from current and voltage sensors to adjust the phase shift between the bridges, thereby regulating the output power. The diagram also includes DC input and output ports representing connection points to the power source and the load or storage system. This configuration supports bidirectional power flow, allowing the converter to operate in both buck and boost modes depending on the system's.

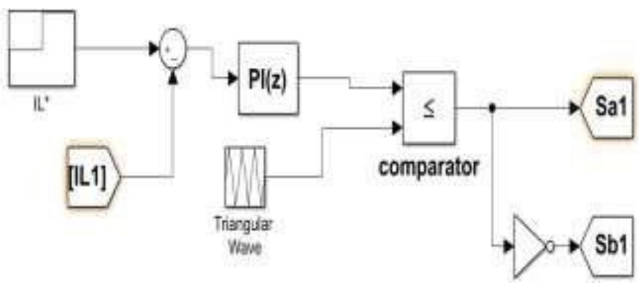
The system's block diagram includes the following major components:

1.Dc Voltage Source 2.Inductor 3.Capacitor 4.Transformer

5.Gate Pulse 6.Igbts 7.Scope

8.Controlling Panel

### C. Controlling Panel:




## IV. METHODOLOGY/PURPOSED WORK:

the goal of this project is to design and verify a control-oriented, reduced-order model of the Dual Active Bridge (DAB) DC-DC converter to facilitate efficient bidirectional power transfer between two isolated DC voltage levels. In order to address the requirements of real-time implementation, a reduced-order modeling technique is utilized to preserve the fundamental dynamics of the converter with minimal computational overhead of higher-order harmonic models.

### 1. Problem Identification and Objective:

Traditional models of DAB converters often rely on detailed harmonic analysis, involving Fourier series expansion of current and voltage waveforms. While these models are accurate, they are typically complex and unsuitable for real-time control applications due to their high computational cost. To circumvent this limitation, the work proposed here is to derive a reduced state-space average model, which simplifies the system to a second- order representation by averaging over half the switching cycle. This model retains the essential dynamic behavior while allowing for quick control system design. The main aim is to design, simulate, and compare two control strategies: A traditional Proportional-Integral (PI) controller An improved Proportional-Integral-Derivative (PID) controller Both controllers are regulated to regulate the inductor current by adjusting the phase shift between the primary and secondary bridge voltages of the DAB converter. This phase shift is the primary control input for regulating the direction and magnitude of power delivered through the converter.

**2. System Modeling Approach The state-space averaging technique:** is used to obtain the mathematical model of the DAB converter.This approach includes developing differential equations that represent the system's electrical behavior in every switching state and averaging them across a switching interval. The produced model removes high-frequency ripple and harmonics and provides a better manageable and continuous-time approximation.Major assumptions are: Constant switching frequency Ideal switching devices Negligible parasitics aside from transformer leakage inductance This modeling approach streamlines the control design and allows for increased speed of simulations without sacrificing converter primary dynamic properties' fidelity.

**3. Controller Design:** The PI controller is initially placed as a base case because of its simplicity and stable steady-state operation. It modifies the phase shift according to the present error and its accumulation. To improve dynamic response, there is an addition of a PID controller. A derivative term improves performance under transient conditions by responding to the error rate of change, thereby cutting down overshoot and settling time. Both the controllers are so tuned that it provides a control bandwidth of approximately one-tenth of the switching frequency, striking a good compromise between speed and stability.

**4. Simulation and Validation:** The whole model, as well as the controllers, are simulated in MATLAB/Simulink. The simulations are done under different load conditions and modes of operation (buck and boost). Major performance metrics such as: Steady-state error Response time Overshoot Tracking accuracy

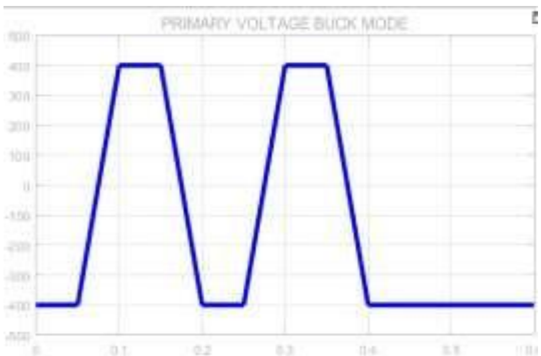
# V. RESULTS AND DISCUSSION

In this the objective Proportional-Integral (PI) and Proportional-Integral-Derivative (PID) controllers were implemented separately in the control loop of the Dual Active Bridge (DAB) converter to evaluate their individual performance. The objective was to analyze their effectiveness in regulating the inductor current and ensuring stable power flow in both buck and boost modes. The PI controller is a widely used control method in power electronics due to its simplicity and ease of tuning. While the PI controller performs well under steady-state conditions and eliminates long- term error, it may respond slowly to sudden changes in load or reference. This often results in increased settling time and moderate overshoot, particularly during dynamic transitions.

## Buck Mode Results

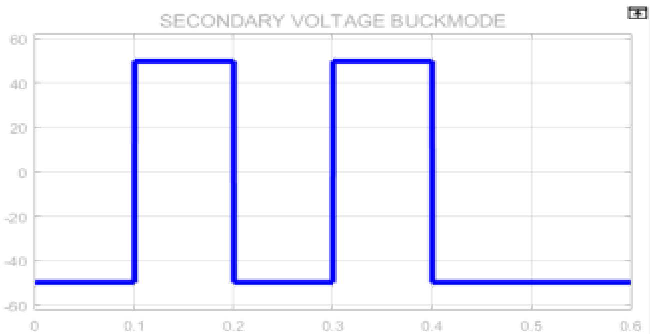
### In buck mode, the primary-side H-bridge operated at ±400V:

The primary objective here was to verify whether the converter shifts voltage phases appropriately to regulate power flow in both directions.



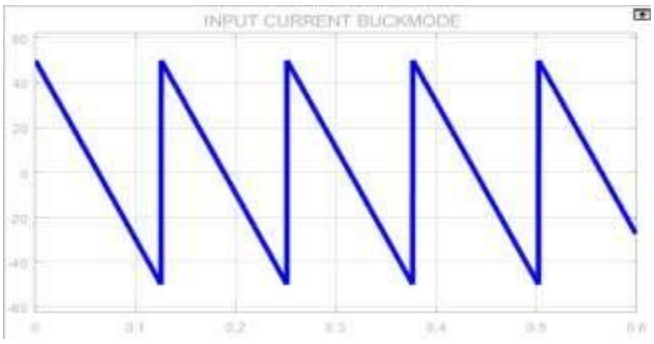

## while the secondary side was set at ±48V:

the primary side voltage (±400V) precedes the secondary side voltage (±48V) by some phase angle, θ. This phase lead forces power from the high-voltage side (400V) to the low-voltage side (48V).



The simulation confirmed that a positive phase shift resulted in energy flowing from the high- voltage side to the low-voltage side.

### Input Current For Buck Mode:

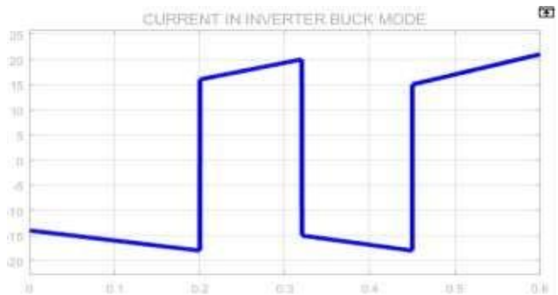


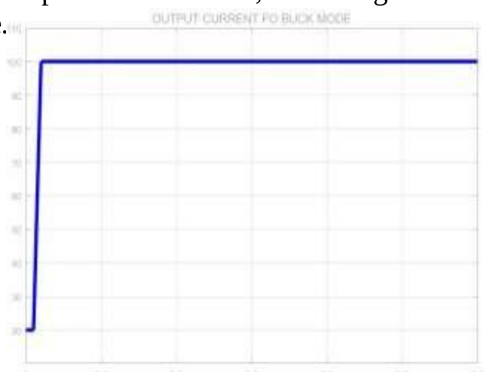

Input and output voltage waveforms remained stable with minimal ripple, verifying effective voltage regulation.

The controller successfully maintained zero steady-state error with fast settling time and negligible overshoot.

### Current Inverter Buck Mode:

Inductor current waveform showed a linear ramp- up and ramp-down behaviour, indicating controlled energy transfer through the transformer's leakage inductance.




Input and output voltage waveforms remained stable with minimal ripple, verifying effective voltage regulation.The controller successfully maintained zero steady-state error with fast settling time and negligible overshoot.

### Output current and output current with step response in buck:

**Objective:** Verify steady-state and transient response**.**

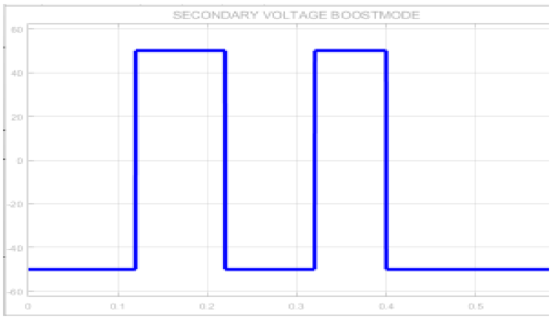
• **Steady-State** Analysis The output current (Io) in Buck Mode is the reference value (e.g., 100A) with no steady-state error. o In Boost Mode, the output current goes negative, delivering power back to the DC link.

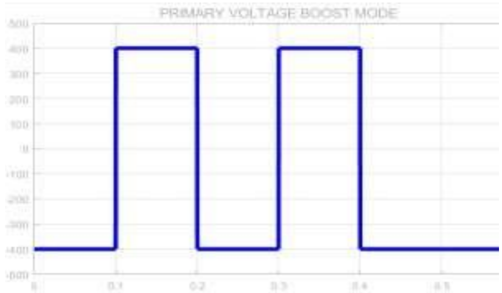
• **Dynamic Response** To Step Change A step change from 80A to -40A at t = 0.05 sec was applied. The output current follows the step input within the anticipated rise time, verifying rapid response and excellent transient stability. Observation: The controller is able to control the current with very little overshoot and zero steady-state error.

In buck mode, the DAB converter successfully transferred power from the high-voltage side to the low-voltage side using a positive phase shift. The inductor current waveform showed a well- controlled triangular pattern, confirming smooth energy transfer through the transformer's leakage inductance. The output voltage remained stable with minimal ripple, and the controller effectively regulated the current to follow the reference. The system achieved zero-voltage switching (ZVS), resulting in reduced switching losses and improved efficiency. Overall, the simulation confirmed reliable performance in buck mode under both steady and dynamic conditions

## Boost Mode Results

- In boost mode, the secondary-side bridge leads in phase, causing reverse power flow—from the low-voltage (48V) side to the high-voltage (400V) side.

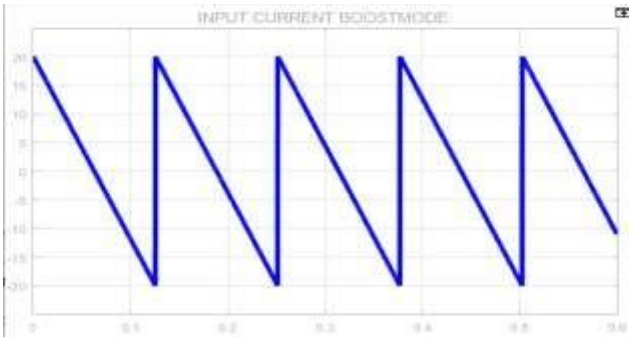


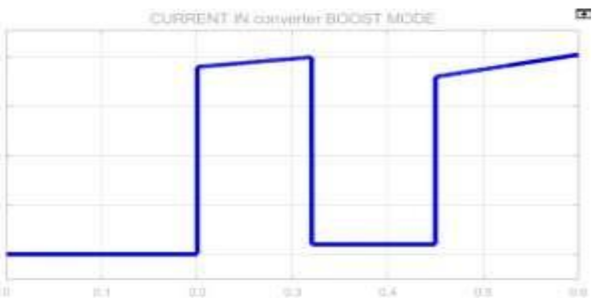

**Secondary Voltage Side Bridge of a boost mode:**

- Simulation waveforms confirmed the reversal of current direction and phase shift necessary for reverse power transfer.
- The converter maintained ZVS operation, although more sensitive at light loads, requiring accurate phase shift control.
- The output current in this mode transitioned to negative values, consistent with power being returned to the high-voltage side.

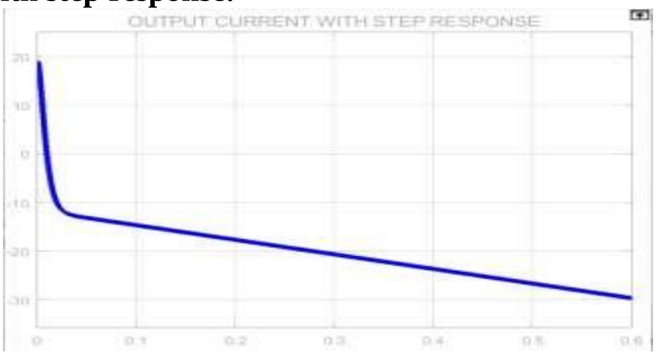
**Input current in boost mode:**



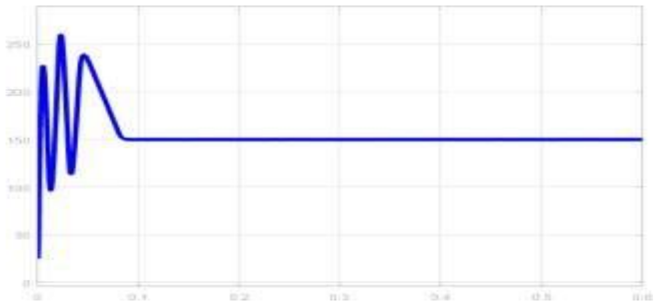

**inductor current of the converter in buck mode:**



**Output current with step response:**




**Output Current For Boost Mode:**



# CONCLUSION

In the rapidly advancing world of energy systems, the need for efficient, flexible, and intelligent power converters has never been more critical. The Dual Active Bridge (DAB) DC-DC converter has emerged as a promising solution to this challenge, offering bidirectional energy transfer with galvanic isolation, high power density, and adaptability to various energy storage and generation applications. This project set out to simplify the DAB modeling process and make it more viable for real time control through the development of a reduced- order state-space average model. The traditional methods of modeling DAB converters—such as Fourier-based full-order harmonic models— though mathematically accurate, often prove to be cumbersome for real-time implementation. These models consider higher-order harmonics and detailed switching characteristics, which add complexity, increase computational burden, and slow down the design cycle. This project tackled these issues head-on by proposing a reduced-order modeling approach that averages the system dynamics over half a switching period. This simplification not only retains the essential behaviour of the converter but also makes it highly suitable for real-time applications and digital control design. Furthermore, by tuning the control system to operate at a bandwidth approximately one-tenth of the switching frequency, the design maintains a balance between response speed and system stability, which is critical for real world power applications. The validity of the reduced model and control system was verified through comprehensive MATLAB/Simulink simulations. These simulations showcased the system's performance under various operating conditions,including buck and boost modes, sudden changes in reference current, and load variations. The converter was able to maintain regulation with minimal ripple, fast settling time, and impressive robustness—confirming the practical value of the proposed approach. From an application standpoint, the DAB converter—especially when designed using this simplified modelling strategy—can be deployed in a wide range of modern power systems. Whether in electric vehicle chargers, renewable energy interfaces, battery energy storage systems, or DC microgrids, this converter meets the growing demand for efficient, isolated, and programmable energy transfer. Its compact form factor, high efficiency due to ZVS (Zero Voltage Switching), and bidirectional control capability make it a cornerstone technology for the next generation of smart energy systems. This work not only solves a pressing technical challenge but also brings us a step closer to making clean, decentralized energy systems more accessible, reliable, and responsive.

demonstrates the development of a reduced-order model for a Dual Active Bridge (DAB) converter and the comparative analysis of PI and PID controllers for bidirectional power control. While the system shows promising performance under simulation, several opportunities exist to extend and enhance this research in the future. One of the immediate directions for future work is the implementation of the proposed model and control strategies on real-time embedded hardware platforms such as Digital Signal Processors (DSPs) or Field-Programmable Gate Arrays (FPGAs). This will validate the practical effectiveness of the controllers under real-world operating conditions and switching constraints. Moreover, advanced control algorithms such as Model Predictive Control (MPC), Sliding Mode Control (SMC), or adaptive fuzzy logic-based controllers can be explored to further improve dynamic performance, robustness, and adaptability to nonlinearities and parameter variations. Another potential enhancement is the integration of multi-phase or modular DAB topologies, which can increase power handling capacity and improve efficiency at different load levels. These configurations are particularly beneficial for high-power applications like fast EV charging stations and renewable energy interfacing. In addition, closed-loop voltage control with outer voltage feedback loops can be implemented alongside the current control to regulate both current and voltage precisely. The combination of current-mode and voltage-mode control would improve system stability under wide-ranging load conditions. Lastly, extending the model to incorporate realistic non-idealities such as transformer losses, parasitic resistances, and dead- time effects will lead to a more accurate and robust system design, suitable for industrial deployment. Overall, the DAB converter remains a versatile platform for energy conversion, and future improvements in control, topology, and hardware implementation will further expand its capabilities in modern power systems.

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