Power Electronics Laboratory Report
Session 4: DC-AC Converter 2

Zbigniew Michalak

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Objectives

- Study the rectifier and inverter mode of the DC/AC power converters.
- Introduce the inductor voltage controller.
- Introduce the DC-Link voltage regulator.

1 Introduction

The objective of this laboratory experiment is to thoroughly investigate the operation of DC/AC power converters in both rectifier and inverter modes, with a particular emphasis on implementing advanced control strategies such as inductor voltage control and DC-Link voltage regulation. Through the design and application of resonant and PI controllers, the experiment aims to achieve accurate regulation of sinusoidal inductor currents synchronized with the grid frequency and to maintain a stable DC-Link voltage by managing the active and reactive power exchanged with the grid appropriately.

2 Part 1: Inductor Current Control Using Resonant Controller

2.1 Task 1: Implementation of the Converter and Control Loop

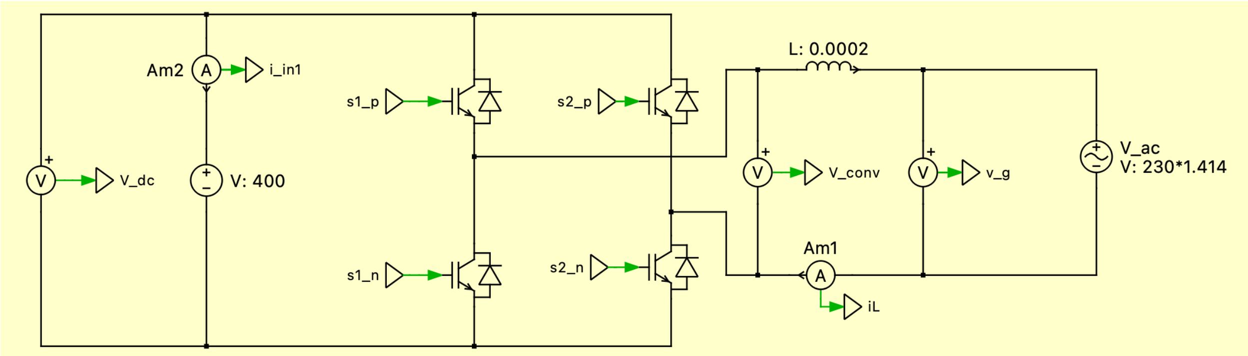

Figure 1: H-Bridge converter with inductor filter.

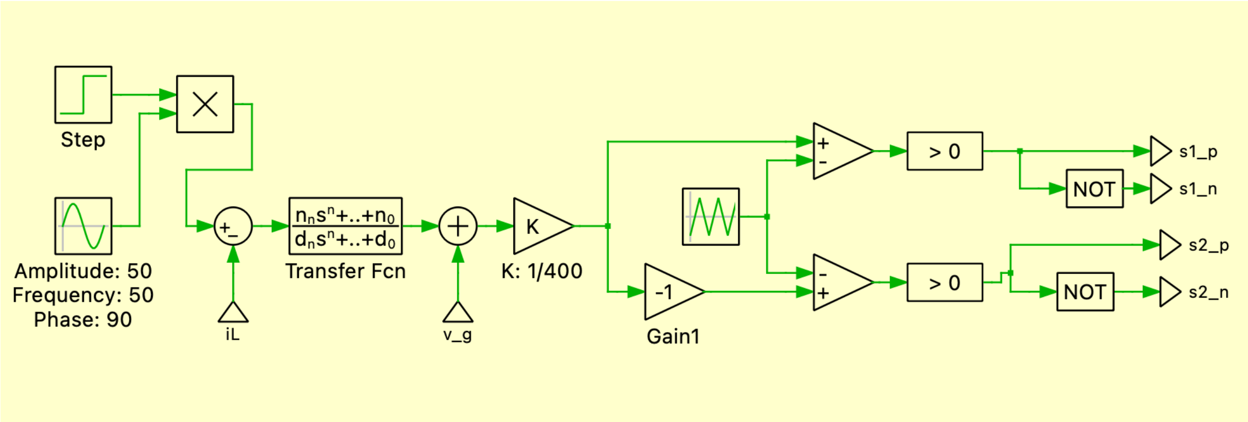

Figure 2: Inductor current control diagram.

The PLECS implementation of the H-Bridge converter circuit is shown in Figure 1, and the corresponding inductor current control loop is detailed in Figure 2.

2.2 Task 2: Current Reference 100A, 50Hz – Transient Response

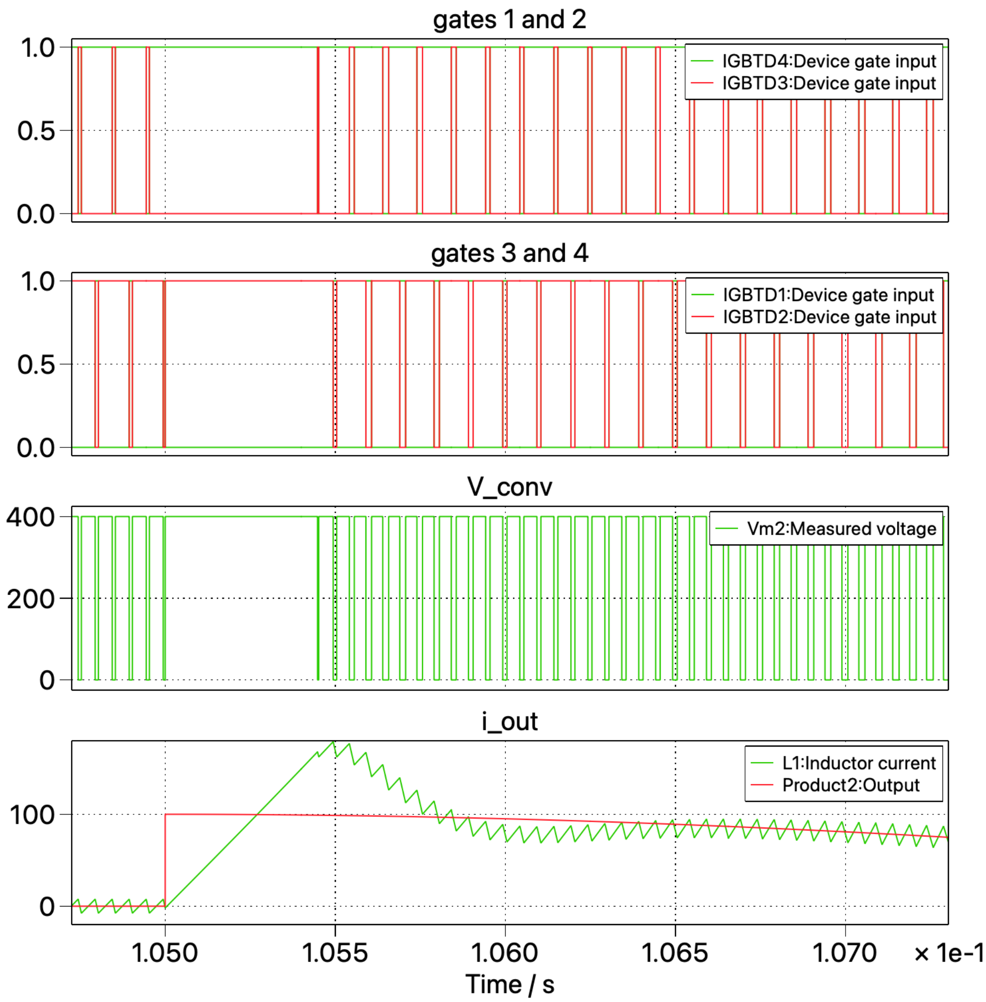

Figure 3: Transient response of the inductor current with 100A, 50Hz reference.

Observations: Figure 3 illustrates the transient behavior of the inductor current and control signals.

2.3 Task 3: Steady-State Response for Different Current References

The system was simulated with a 50A, 50Hz current reference under six different phase shift conditions relative to the grid voltage. The steady-state inductor current (i_L) and grid voltage (v_g) waveforms for these six phase shift conditions are presented in Figures 4 through 9.

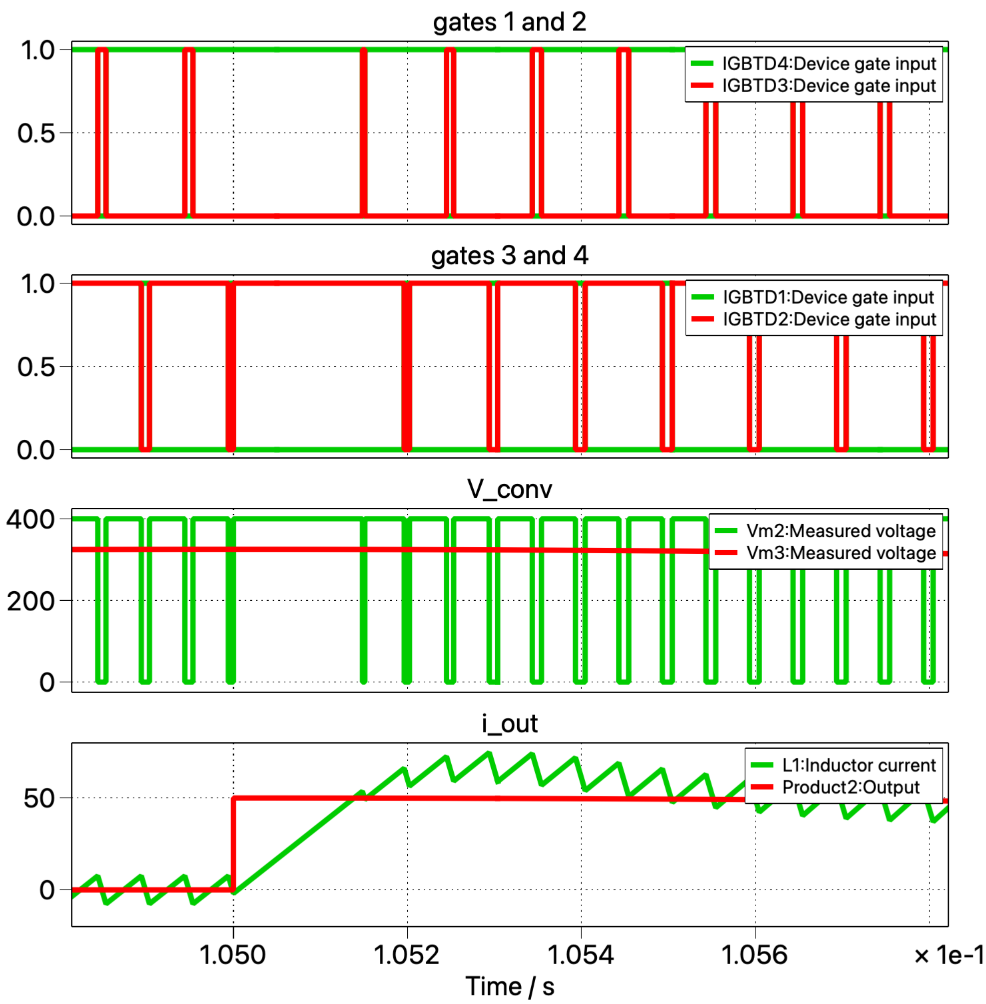

Figure 4: Steady-state waveforms for 50A, 50Hz reference, 0° phase shift (in phase).

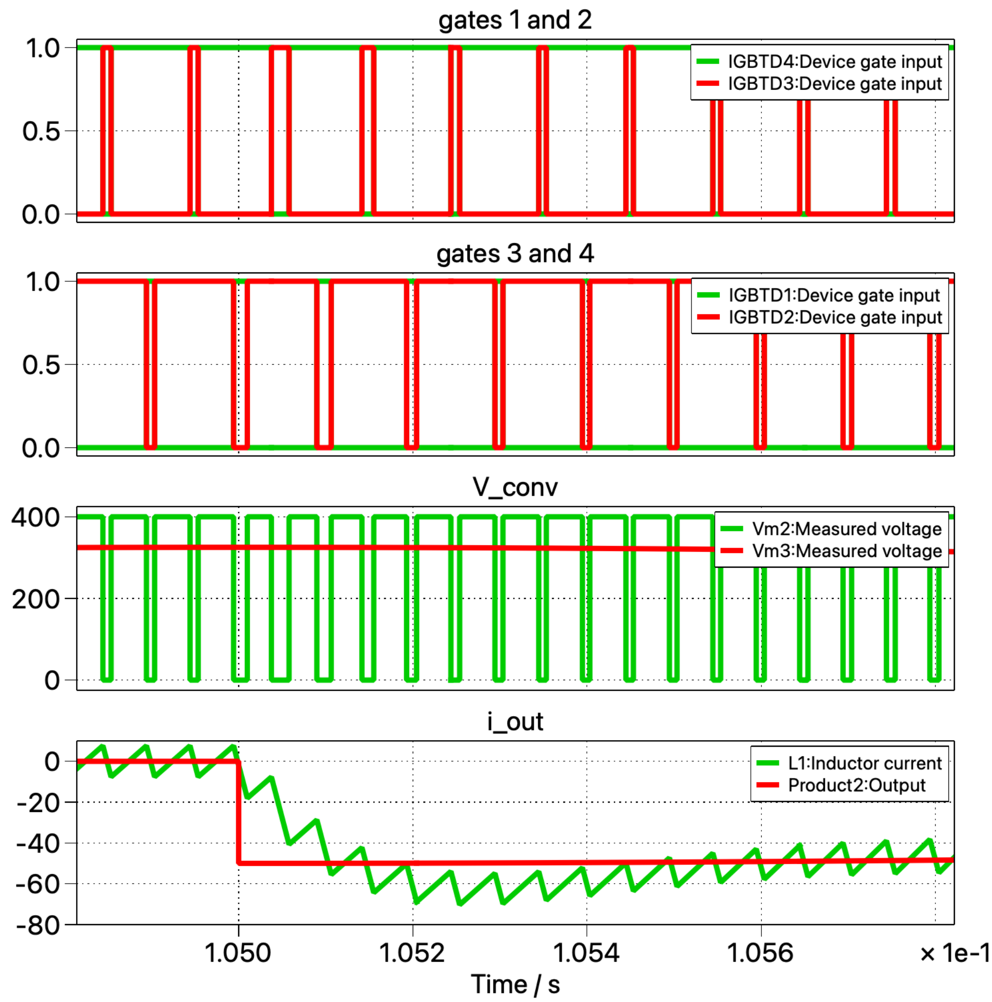

Figure 5: Steady-state waveforms for 50A, 50Hz reference, 180° phase shift (counter phase).

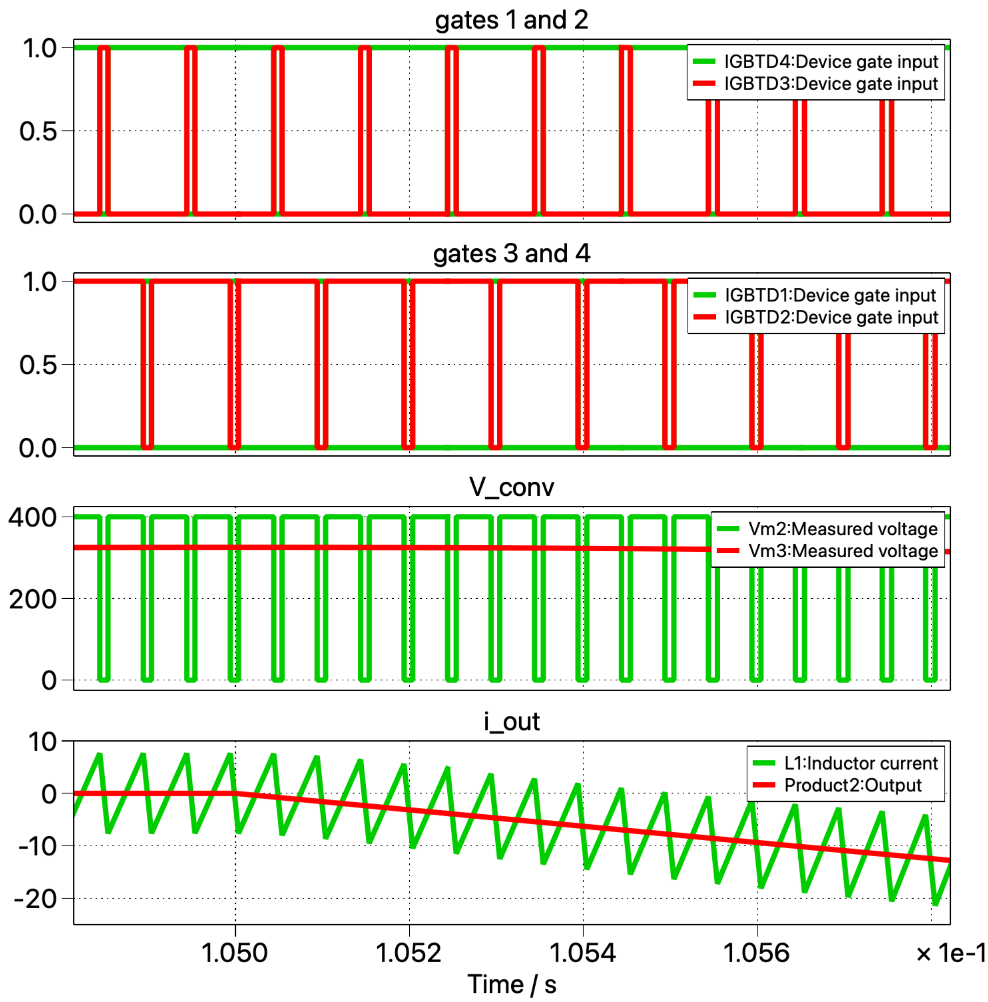

Figure 6: Steady-state waveforms for 50A, 50Hz reference, +90° phase shift.

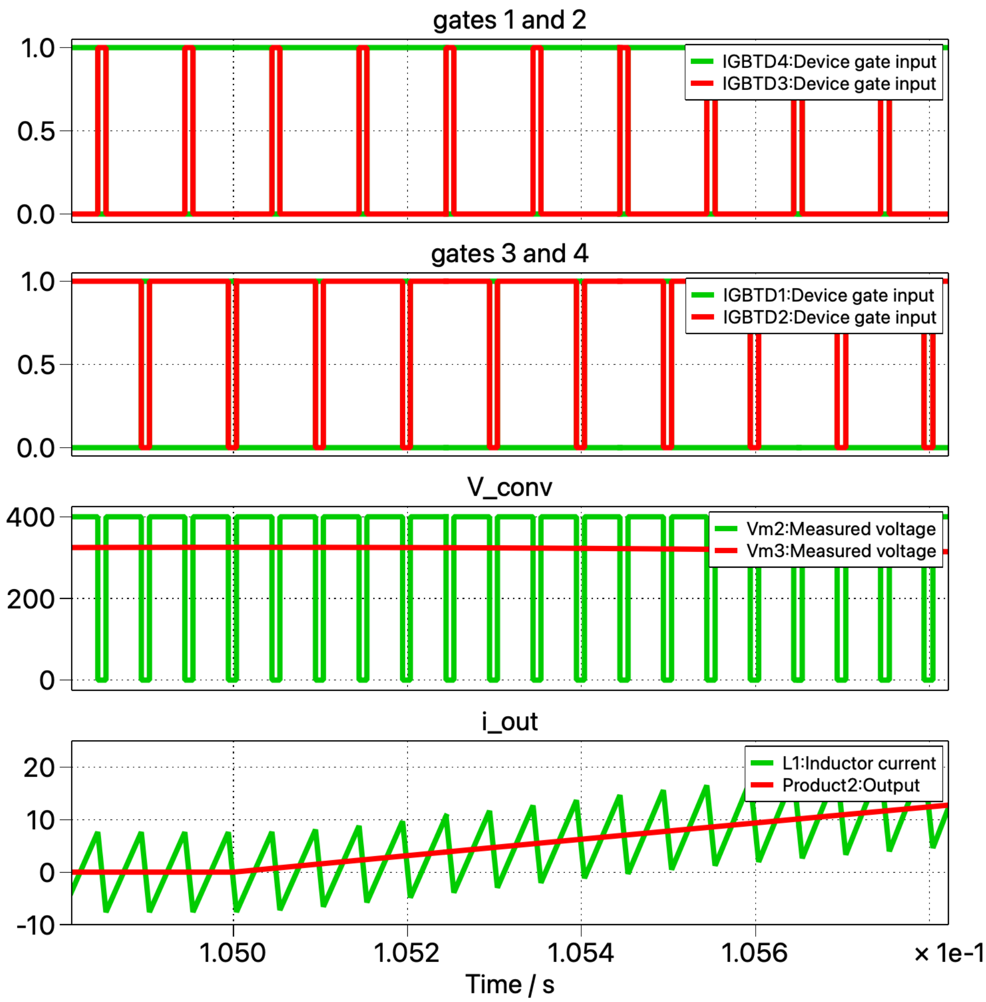

Figure 7: Steady-state waveforms for 50A, 50Hz reference, $-90°$ phase shift.

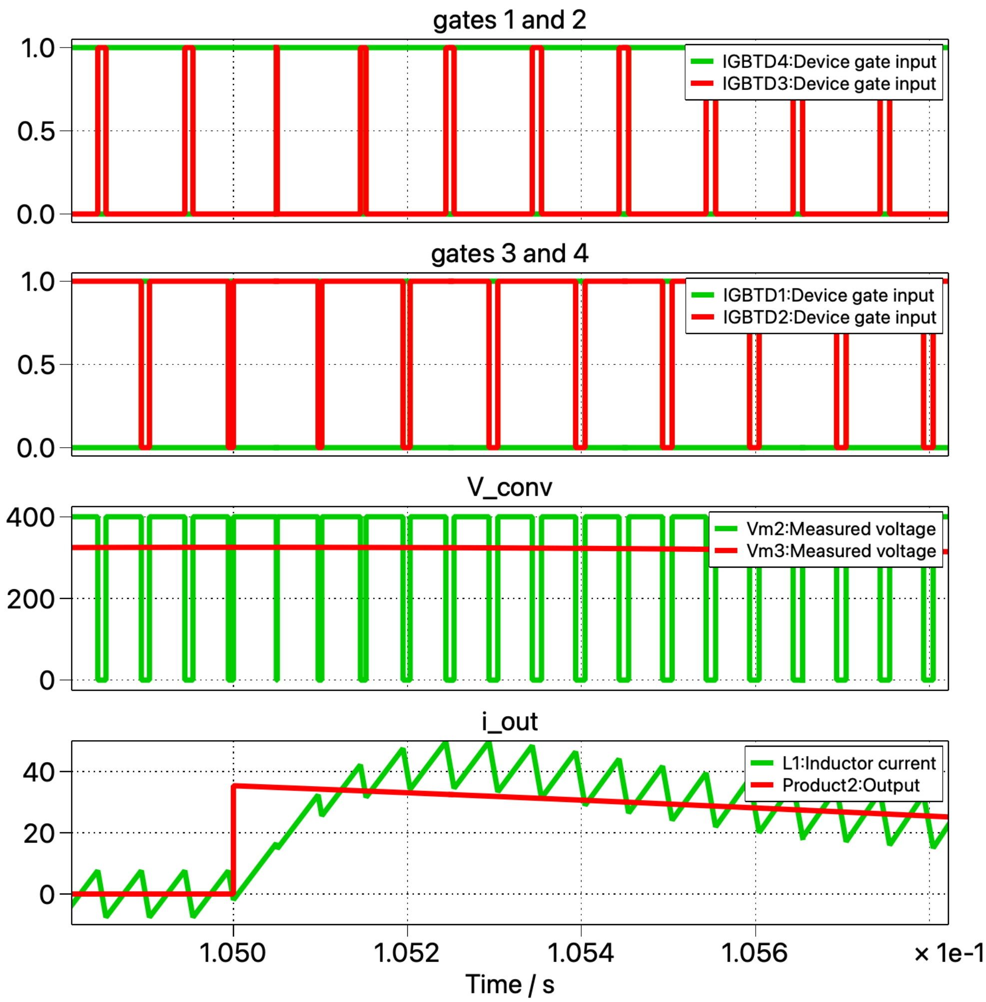

Figure 8: Steady-state waveforms for 50A, 50Hz reference, +45° phase shift.

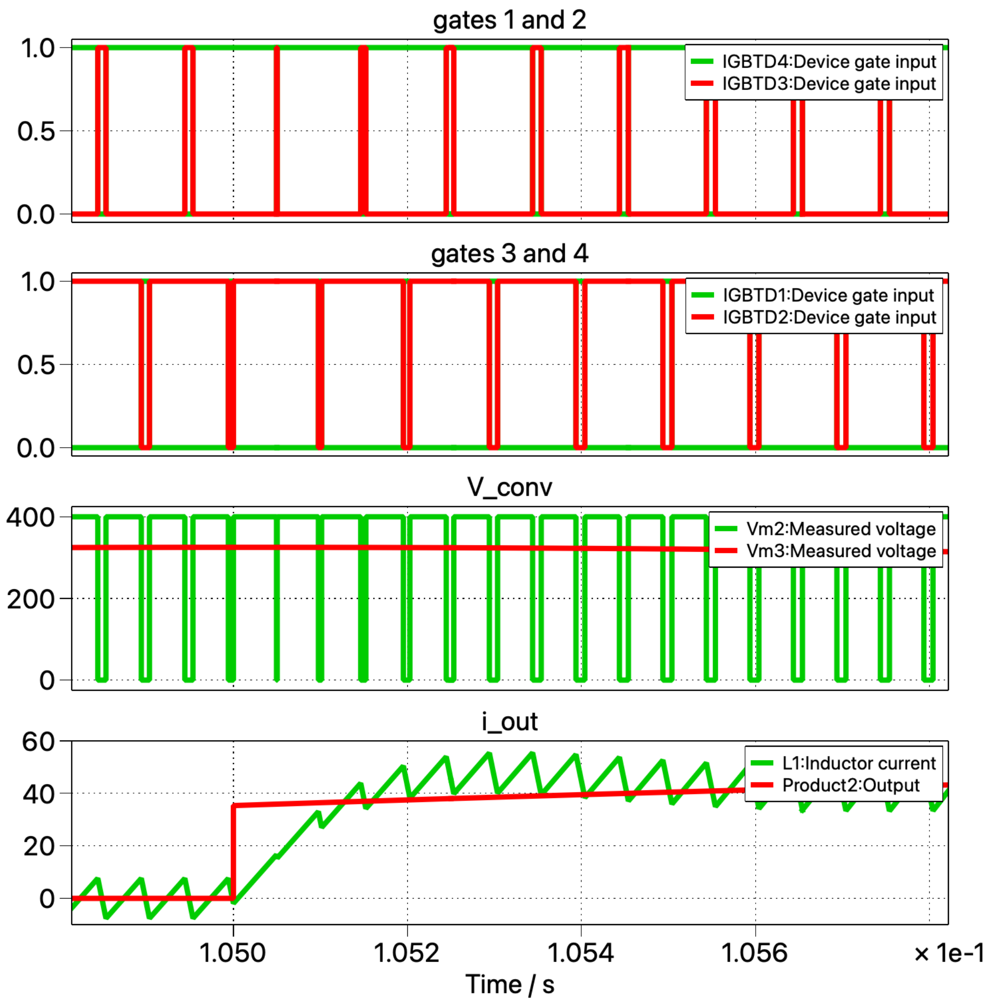

Figure 9: Steady-state waveforms for 50A, 50Hz reference, $-45°$ phase shift.

2.4 Task 4: Active Power Calculations for Different Current References

The standard formula for calculating active power under sinusoidal steady-state conditions is:

$$P = V_{\text{rms}} I_{\text{rms}} \cos(\phi) \tag{1}$$

Where:

- $V_{\text{rms}} = 230\,\text{V}$ is the grid voltage (given).
- $I_{\text{rms}} = 50\,\text{A}$ is the magnitude of the current reference.
- ϕ is the phase difference between current and voltage, as observed in Figures 4-9.

The DC-side power is computed from the average value of instantaneous power using:

$$P_{\text{DC}} = V_{\text{DC}} \cdot I_{\text{DC}} \tag{2}$$

Assuming ideal conditions and no internal losses, $P_{\text{DC}} \approx P_{\text{grid}}$ in magnitude.

Table 1: Calculated Active Power for Different Phase Shifts

Phase Shift	$\cos(\phi)$	P_{grid} (W)	P_{DC} (W)
0°	1	$230 \times 50 \times 1 = \mathbf{11{,}500}$	11,500
180°	–1	$230 \times 50 \times (-1) = \mathbf{-11{,}500}$	–11,500
+90°	0	$230 \times 50 \times 0 = \mathbf{0}$	0
−90°	0	$230 \times 50 \times 0 = \mathbf{0}$	0
+45°	0.7071	$230 \times 50 \times 0.7071 \approx \mathbf{8{,}143}$	8,143
−45°	0.7071	$230 \times 50 \times 0.7071 \approx \mathbf{8{,}143}$	8,143

Assumption: The converter is ideal and lossless, meaning that the active power on the DC side equals the active power delivered or absorbed by the grid.
Note: Positive power indicates power injected into the grid; negative values represent power absorbed from the grid.

2.5 Task 5: Grid Voltage Disturbance Test

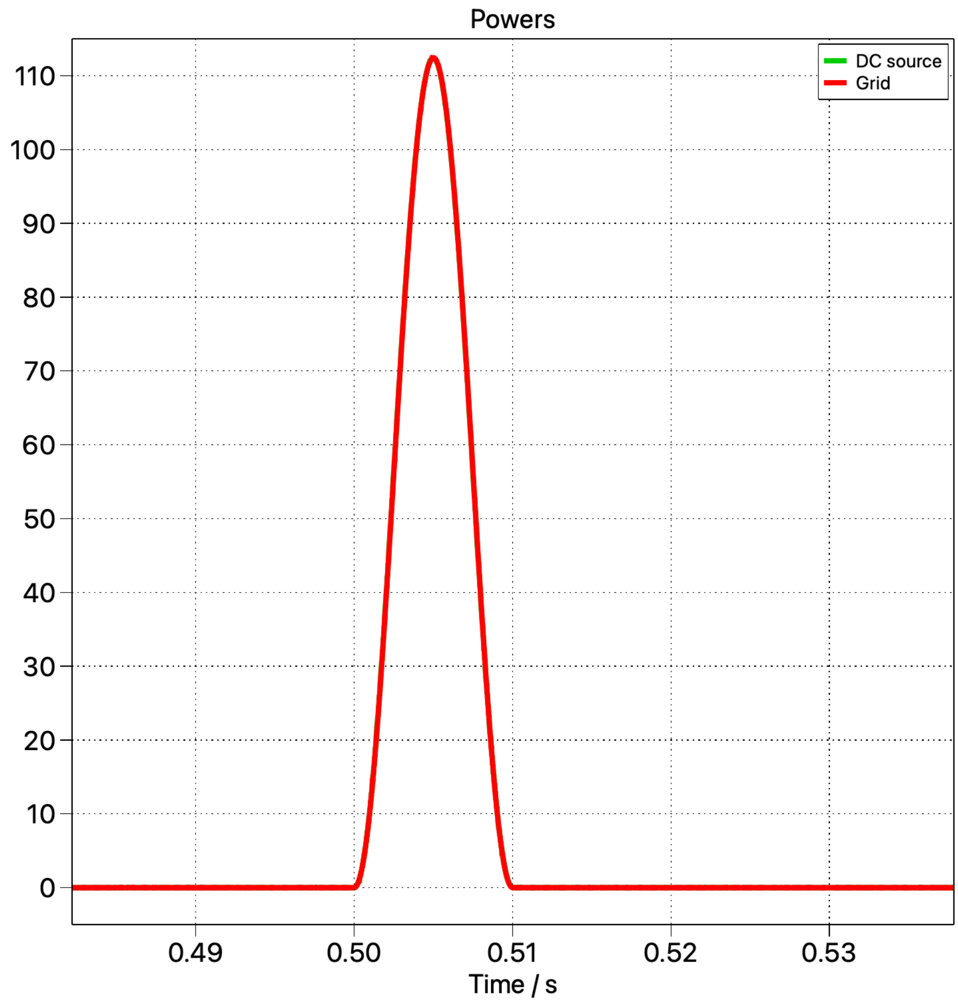

Figure 10: Power transient under a 10V grid voltage disturbance for 90° phase shift of the current reference (50A 50Hz).

The transient active power spike observed in Figure 10 (0W to 110W and back to 0W) during the grid voltage disturbance, while operating with a 90° current phase shift, is expected. It represents the momentary energy exchange required for the controller to reject the disturbance and re-establish the zero-average-active-power (purely reactive) condition. The rapid return to zero power indicates successful controller action.

2.6 Task 6: Critical Grid Voltage Test

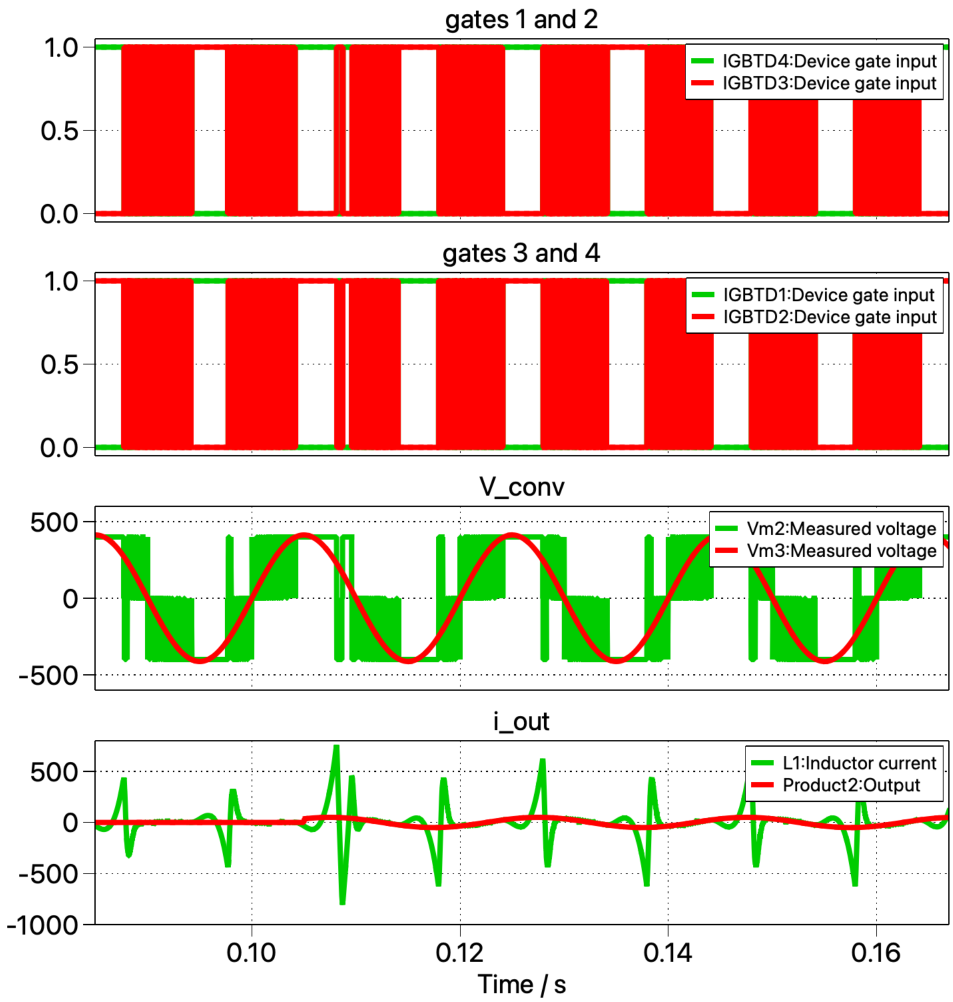

Figure 11: Inductor current behavior at magnitude of 292V grid voltage.

The system loses current regulation when the peak grid voltage approaches a level where the required converter output voltage (v_{conv}) would need to exceed the available DC-Link voltage ($V_{\text{DC}} = 400\,\text{V}$). Theoretically, the absolute maximum grid voltage occurs when the peak grid voltage equals the DC voltage, leading to $V_{\text{g,rms,critical}} \approx V_{\text{DC}}/\sqrt{2} = 400\,\text{V}/\sqrt{2} \approx 282.8\,\text{V}$. In the simulation, the critical voltage was observed around $292\,\text{V}_{\text{rms}}$. This slightly higher value compared to the basic theoretical limit might be attributed to the controller actively compensating for voltage drops or specific characteristics of the unipolar PWM modulation allowing the fundamental output voltage to slightly exceed the simple $V_{\text{DC}}/\sqrt{2}$ limit under certain conditions. Nonetheless, it confirms the direct dependence of the critical grid voltage on the DC-Link voltage limit.

3 Part 2: DC-Link Voltage Control Using PI Regulator

3.1 Controlled Rectifier Implementation

The power converter circuit for Part 2, configured as a controlled bidirectional rectifier, is shown in Figure 12. The corresponding DC-Link voltage control diagram, employing a PI regulator and a notch filter, is depicted in Figure 13.

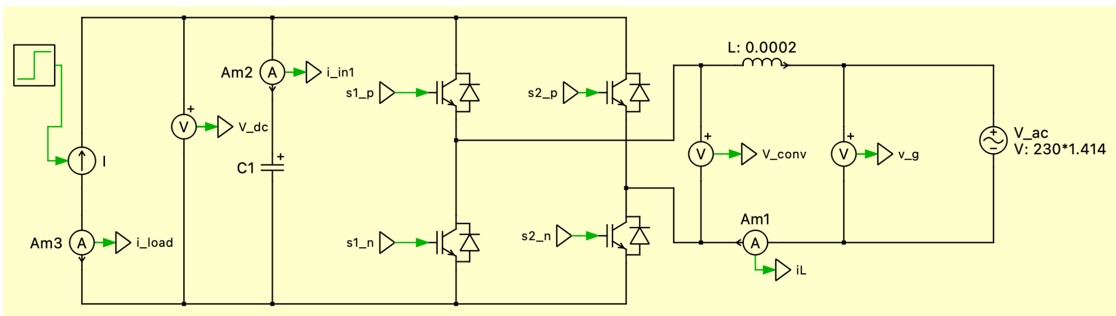

Figure 12: PLECS schematic of the controlled bidirectional rectifier (Part 2).

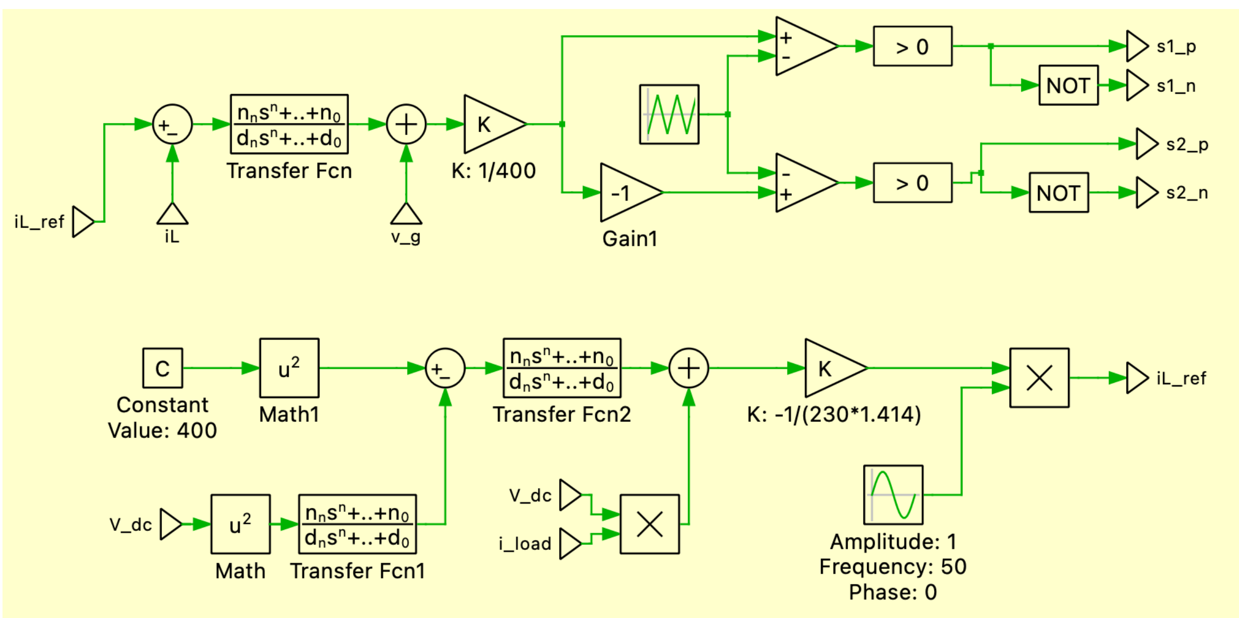

Figure 13: DC-Link voltage control diagram implemented for Part 2.

3.2 Task 1: Passive Diode Bridge Simulation

The power circuit from Figure 12 was simulated with the controller gate signals disconnected, forcing the H-bridge to operate as a passive diode rectifier. The DC-Link voltage (V_{dc}) behavior was observed under three load conditions: 0A, 5A, and -5A.

The simulation results for these passive rectification scenarios are shown in Figures 14, 15, and 16.

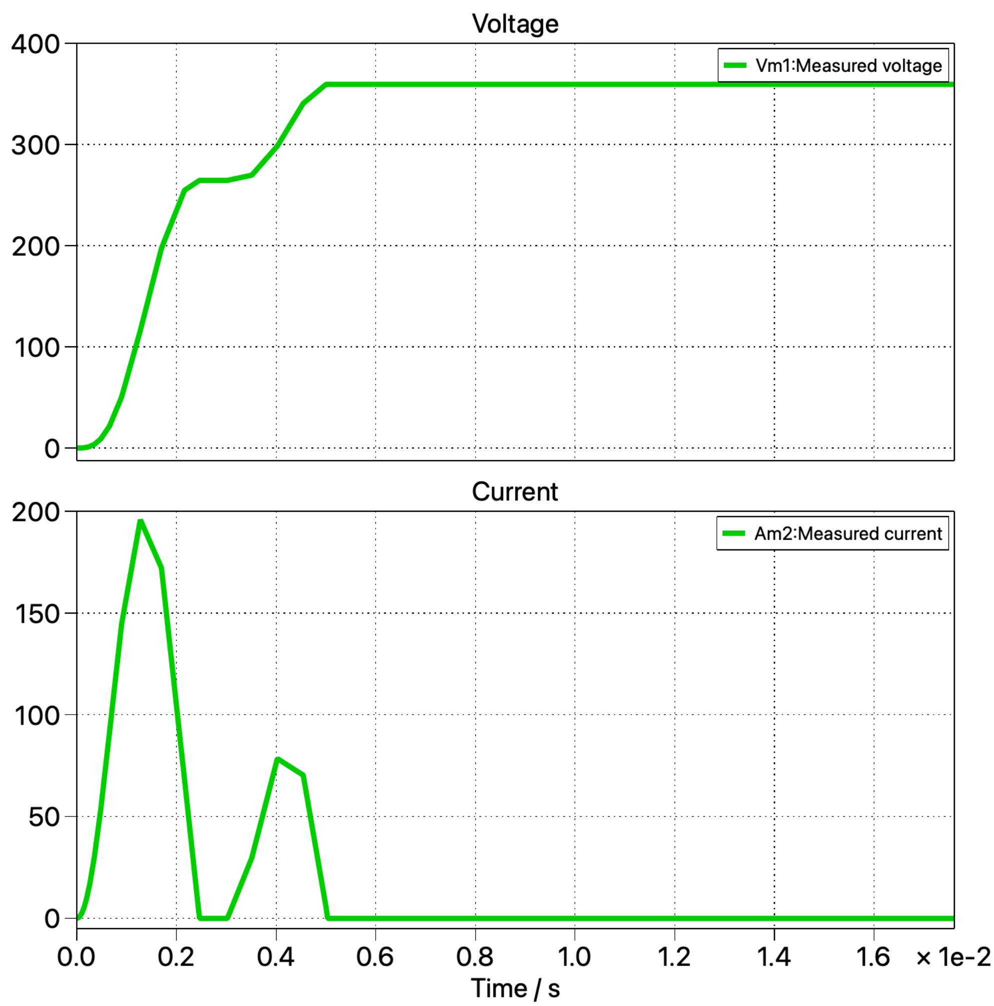

Figure 14: Passive rectifier simulation results with $i_{load} = 0\,\mathrm{A}$. Shows DC-Link voltage (V_{dc}) and capacitor current.

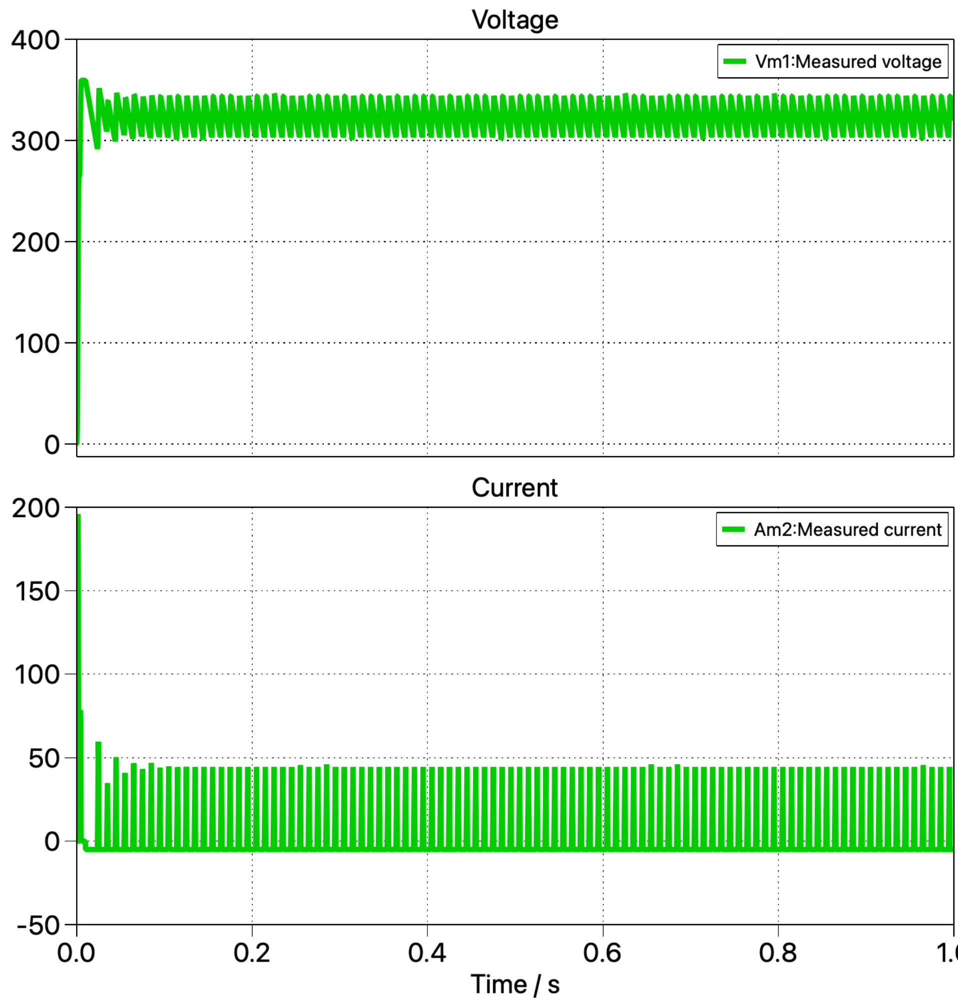

Figure 15: Passive rectifier simulation results with $i_{\text{load}} = 5\,\text{A}$. Shows DC-Link voltage (V_{dc}) and capacitor current.

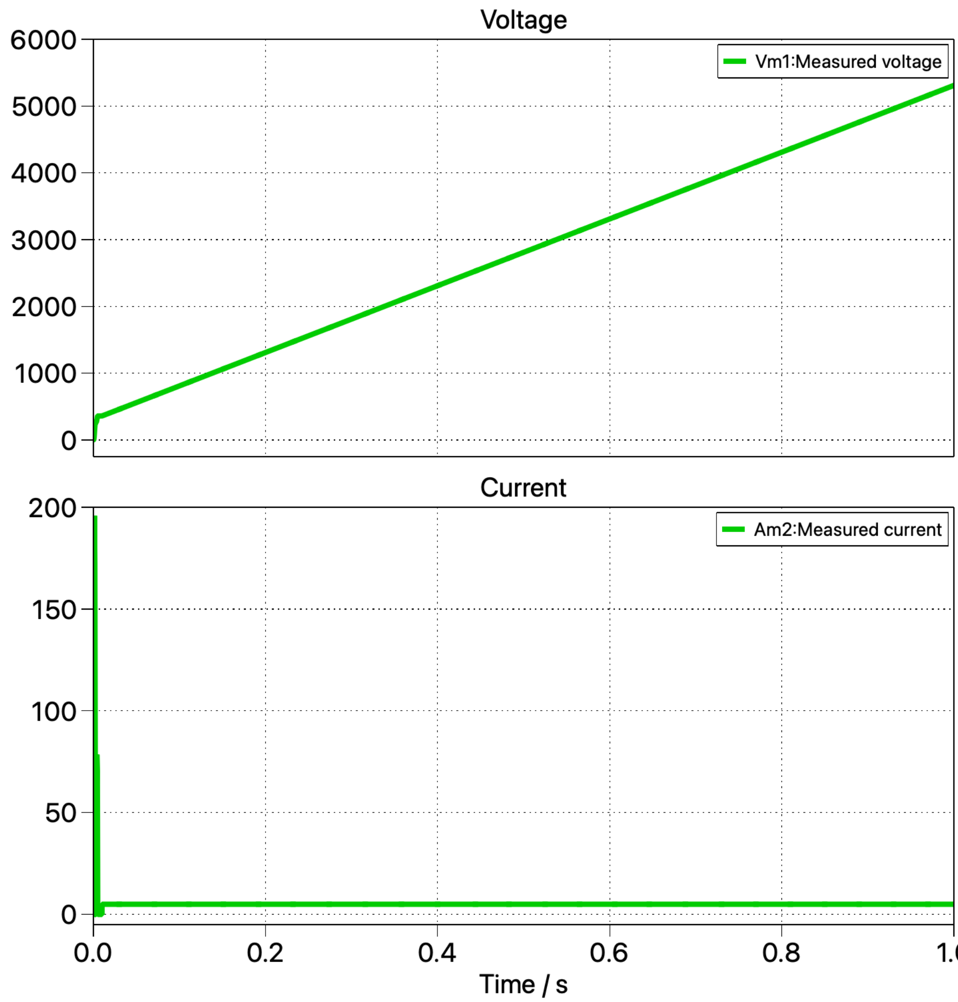

Figure 16: Passive rectifier simulation results attempting $i_{\text{load}} = -5\,\text{A}$.

Observations: With 0A load, the DC voltage settled around 360V. Under 5A load, the average voltage dropped slightly. Attempting a -5A load demonstrated the circuit's inability to operate bidirectionally, as the diodes blocked reverse power flow.

3.3 Task 2: Controlled Rectifier Implementation

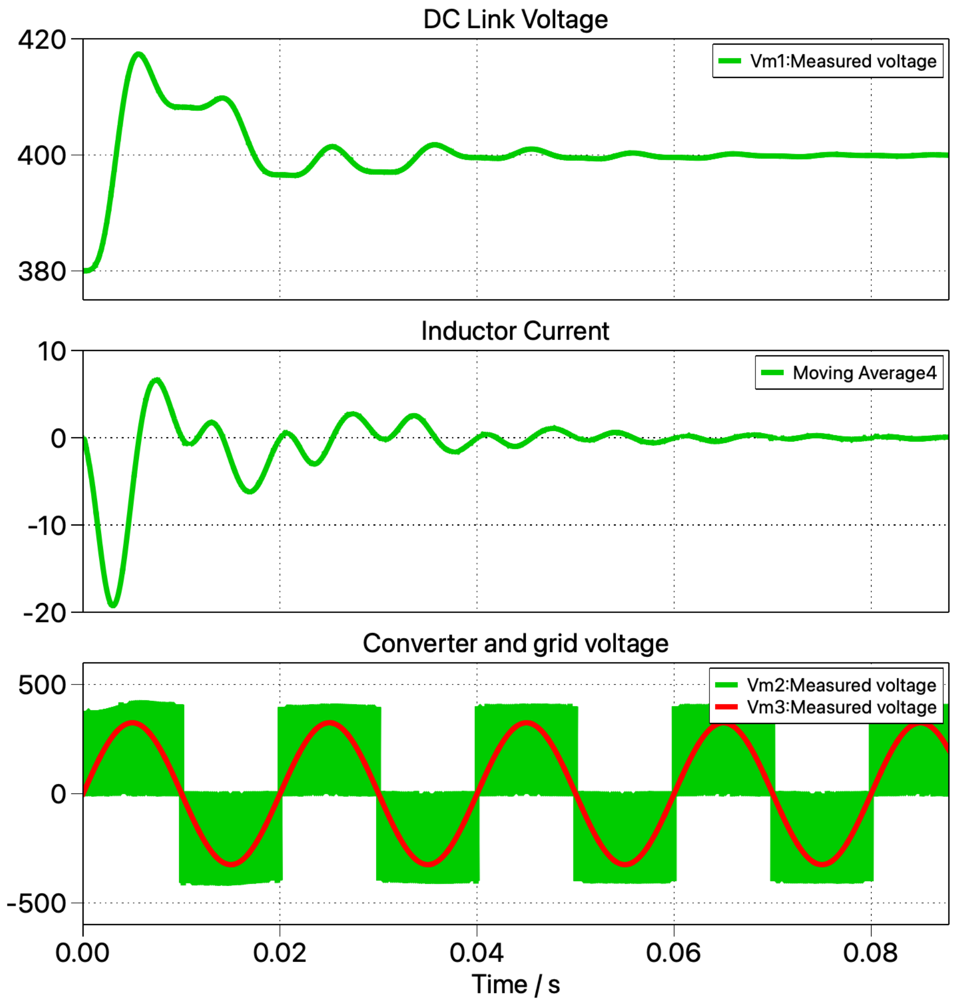

Figure 17: Controlled bidirectional rectifier with PI controller (initial voltage = 380V, reference = 400V).

Observations: Figure 17 shows the DC-Link voltage rising to the reference value under PI control.

3.4 Task 3: Step Response to 420V Reference (No Filter, No Load)

The system's response to this reference step is illustrated in Figure 18.

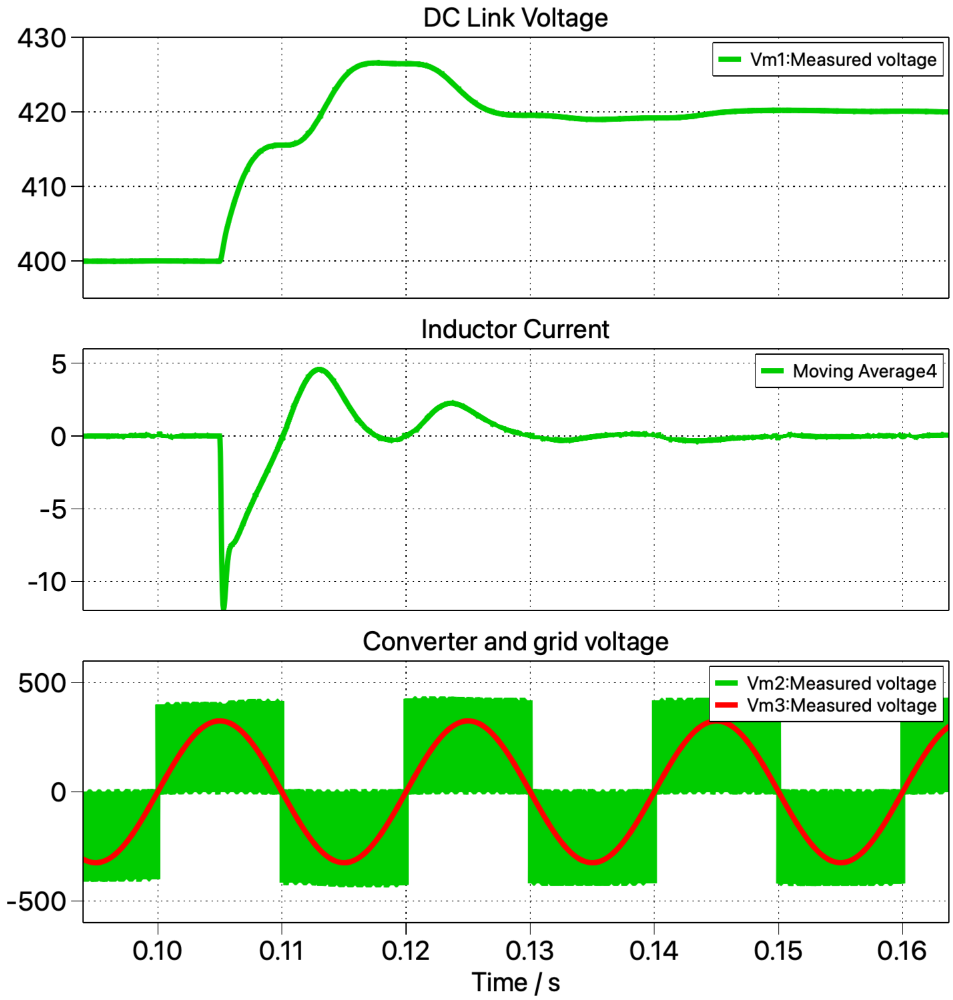

Figure 18: DC-Link voltage step response from 400V to 420V without voltage filter and with no load.

3.5 Task 4: Load Step from 0A to 5A to –5A

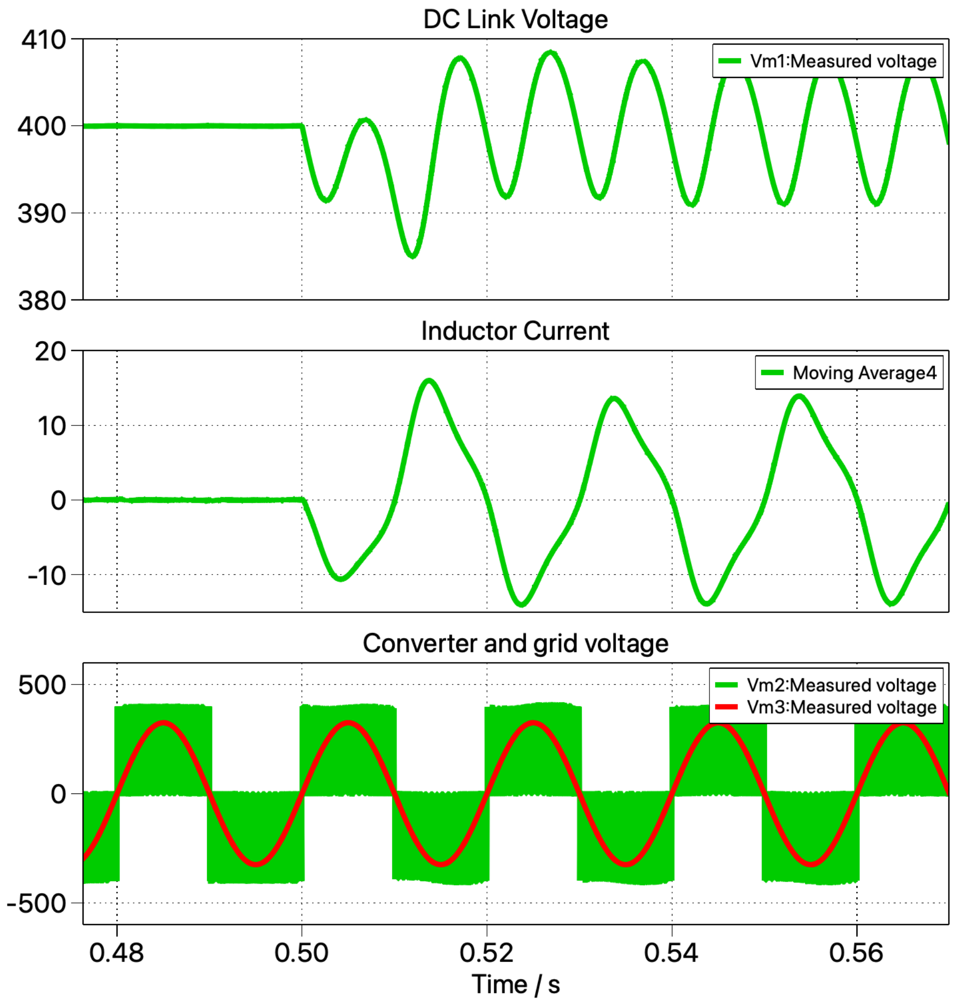

Figure 19: DC-Link voltage response to load current variation from 0A to 5A with no filter.

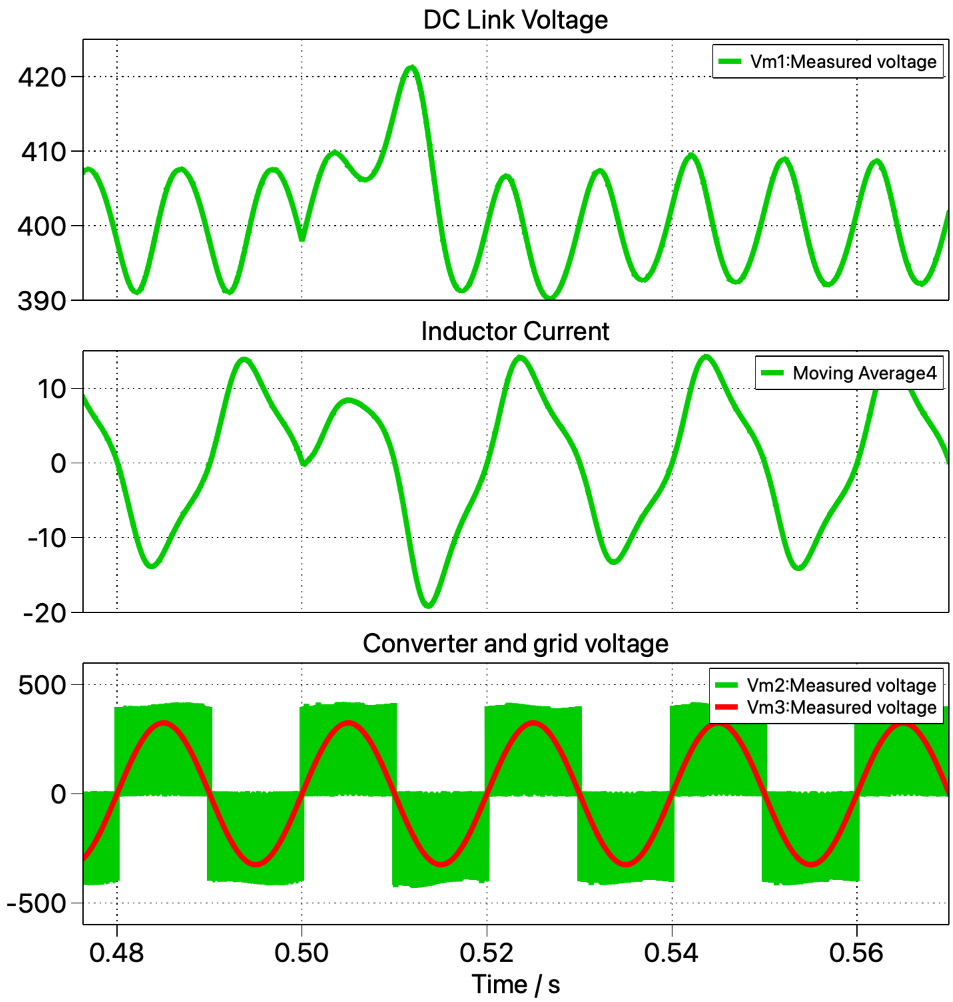

Figure 20: DC-Link voltage response to load current variation from 5A to -5A with no filter.

Observations: In Figures 19 and 20 harmonics are visible in the uneven shape of the current waveform.

3.6 Task 5: Filtered Voltage Response to Load Step

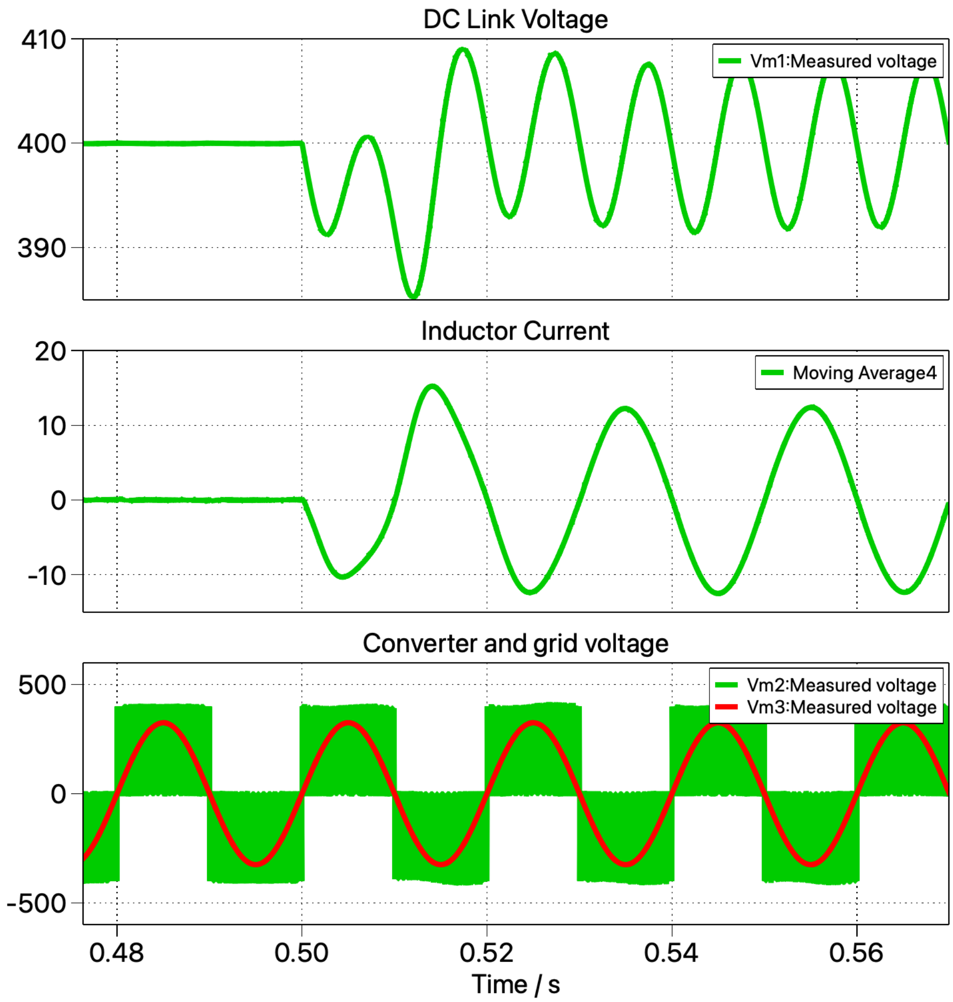

Figure 21: DC-Link voltage response to load current variation from 0A to 5A with filter included.

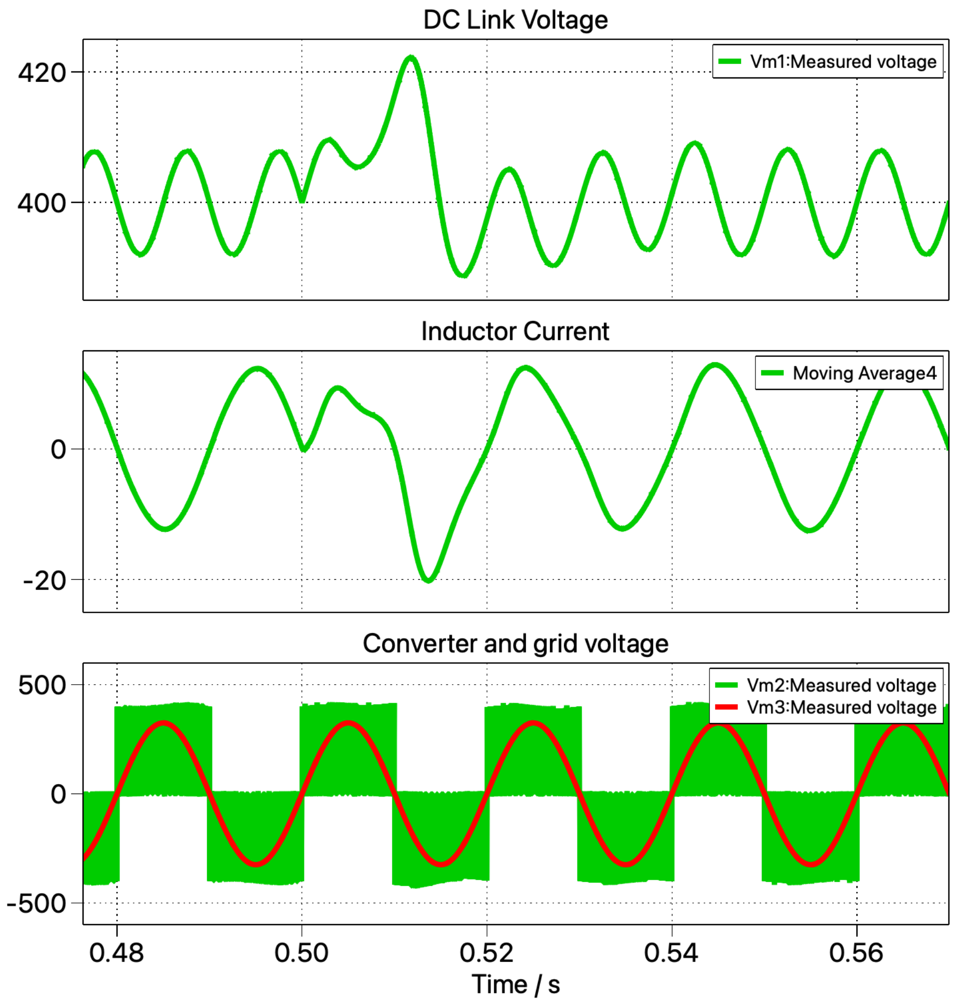

Figure 22: DC-Link voltage response to load current variation from 5A to -5A with filter included.

Observations: Smoothing of the sinusoidal shape of the current is clearly visible in Figure 21 (0A to 5A step) and Figure 22 (5A to -5A step), where the filter was implemented. These figures also show improved voltage regulation compared to the unfiltered case.

Conclusion

In this laboratory session, the operation of DC/AC power converters in both inverter (Part 1) and controlled rectifier (Part 2) modes was investigated.

In Part 1, the converter circuit utilized a resonant controller for inductor current regulation. The controller achieved good transient performance (Figure 3) and accurately tracked sinusoidal references across various phase shifts (Figures 4-9), enabling control over active/reactive power flow. The system demonstrated robustness to grid voltage disturbances (Figure 10) and highlighted the operational limit imposed by the DC-Link voltage (Figure 11).

In Part 2, the setup was modified to a controlled rectifier (Figure 12) employing a PI controller for DC-Link voltage regulation (Figure 13). Passive operation showed limitations (Figures 14-16). The active controller successfully regulated the voltage (Figure 17) and responded to reference changes (Figure 18). Load step tests emphasized the benefit of the voltage notch filter: the unfiltered response (Figures 19, 20) showed significant transients and current distortion, while the filtered response (Figures 21, 22) demonstrated improved voltage stability and current quality.

Overall, the experiments successfully demonstrated fundamental control principles for DC/AC converters, validating the use of resonant and PI controllers and illustrating the impact of system parameters and filtering on performance and stability.