Report on Research Project

Hardware Implementation of Dual-Active Bridge (DAB) Converter for Battery Charging Systems

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Abstract-This report presents the implementation of an isolated Dual Active Bridge (DAB) DC-DC converter for battery charging from single-phase AC. The existing hardware uses an H-bridge to generate DC from AC (controlled via a variac) and two half-bridge inverters driving a high-frequency transformer. Initial tests with square-wave PWM control show that only about 80% of the converter hardware is operating properly: one half-bridge is not contributing expected current, resulting in low load current. We review relevant converter topologies (including standard DAB and novel T-type variations) and limitations of simple ePWM control. Based on insights from recent literature, especially Liu *et al.*'s full-bridge T-type converter vbn.aau.dkvbn.aau.dk, future work will implement a quasi-square T-type waveform on the input bridge. This is expected to extend the soft-switching range and improve power delivery. Detailed hardware descriptions, experimental results (with placeholders for waveforms), and plans for simulation and control development are provided.

Introduction:

Isolated DAB converters are widely used in power electronics for battery and EV charging because they provide bi-directional, galvanically-isolated power transfer with high efficiencynature.com. A typical DAB consists of two H-bridge (or half-bridge) converters connected by a high-frequency transformer. By controlling the relative phase and voltage of each bridge, the converter can regulate real and reactive power flownature.com. The DAB topology is valued in on-board chargers due to its simple structure, bidirectional capability, soft-switching operation, and high power densitynature.com. In practice, one bridge acts as a rectifier (from DC link to transformer) and the other as an inverter (from transformer to output DC), often using phase-shift modulation for power controlnature.comnature.com.

Conventional two-level (full H-bridge) DABs require all switches to withstand the full input voltage, which limits their use at very high voltagesvbn.aau.dk. To handle higher voltages, three-level (TL) topologies have been studied, since these halve the voltage stress on each devicevbn.aau.dk. Among TL variants, the T-type converter has gained attention due to its reduced component count and simpler structure compared to diode-clamped three-level designsvbn.aau.dk. In inverter applications, T-type legs are common, and recent work has proposed T-type isolated DC/DC converters for power applicationsvbn.aau.dkvbn.aau.dk. However, earlier isolated T-type converters used a half-bridge structure, which doubles the current stress on switches and is not suitable for high-power DAB applicationsvbn.aau.dk. The present project uses dual half-bridge converters (a DAB) at moderate power. Nevertheless, the context of high-voltage topologies motivates exploring T-type modulation: Liu *et al.* have demonstrated a full-bridge T-type converter with SiC/Si MOSFETs that achieves wide input range and ZVS by splitting the DC busvbn.aau.dkvbn.aau.dk.

In this project's converter, standard TI C2000 ePWM modules generate fixed-frequency 50% duty square waves to drive each half-bridge. While simple, this control is inflexible: it produces only basic square outputs and relies on fixed timing. Such standard PWM offers limited modulation flexibility (no intermediate voltage levels), which can impede soft-switching or optimal power transfer. In practice we observe one bridge under-delivering current (see below), suggesting the need for an improved gating scheme. Recent research suggests replacing one bridge's square wave with a quasi-square T-type waveform to halve the applied transformer voltage during part of the cyclevbn.aau.dkvbn.aau.dk. This approach (two-step or "T-type" modulation) is expected to widen the ZVS range and balance currents between switches.

Dual Active Bridge Converter:

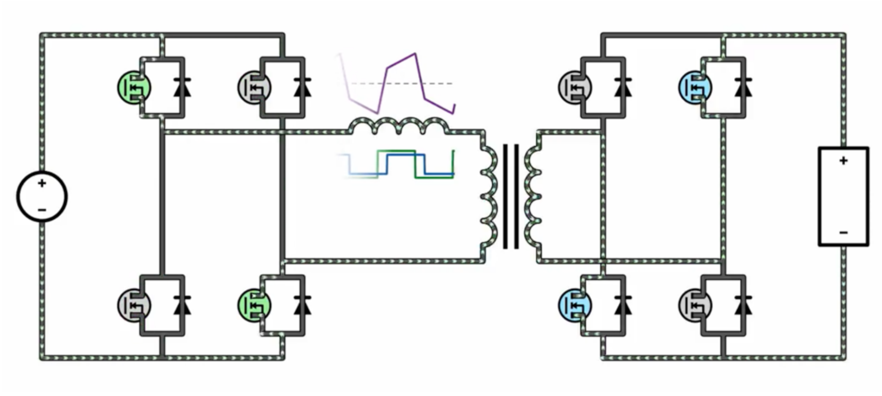

Figure 1. Dual Active Bridge(DAB)

Modes of Operation:

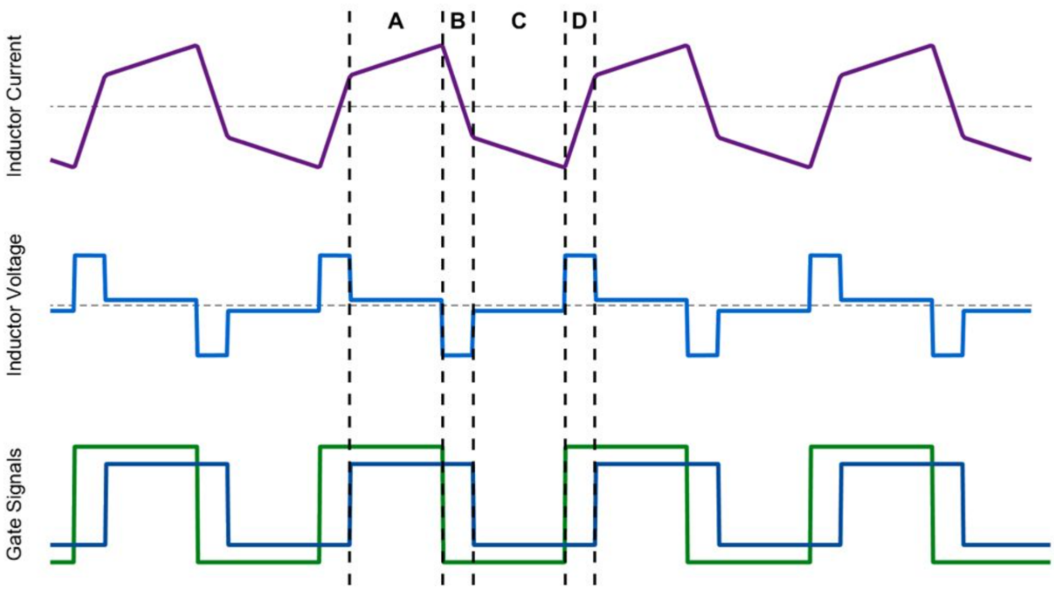

Figure 2. Waveforms of Inductor current, voltage and gating signals of the respective switches

Power flow is primarily achieved in modes A and C, with B and D being necessary to create an AC signal that can transmit power through the high-frequency transformer.

Dual Active Bridge (DAB) Topologies: The traditional DAB uses two full-bridge converters (often single-phase) with a series transformer. Phase-shift modulation between the bridges controls power flow. Advantages include isolation, high efficiency with soft-switching, and bidirectional capability. DABs have been widely studied for EV and renewable energy applications. For example, Rajender *et al.* demonstrate a bi-directional DAB charger with single-phase shift control, achieving broad voltage range and supporting constant-current/constant-voltage modes. In general, simple 50% duty square-wave DAB drives are easy to implement but restrict control to phase shift alone.

Three-Level (TL) and T-Type Variants: To handle higher voltages, three-level DAB converters have been explored. In a three-level (diode-clamped) converter, the half DC-link capacitors each provide half-voltage pulses to the transformer, reducing device stressvbn.aau.dk. Many works focus on soft-switching extension, capacitor balancing, and current reduction in TL DABsvbn.aau.dk. The T-type converter is a variant of three-level topology that replaces clamping diodes with an auxiliary leg (a “T” leg) to create a neutral point. This reduces the number of components and can improve efficiencyvbn.aau.dk. Liu *et al.* propose an isolated full-bridge T-type DC/DC converter composed of 4 high-voltage SiC MOSFETs and 4 low-voltage Si MOSFETsvbn.aau.dk. Compared to conventional three-level converters, their T-type design has a simpler structure and higher efficiency, while achieving zero-voltage switching (ZVS) over a wide input rangevbn.aau.dkvbn.aau.dk. Crucially, their control strategy uses two distinct switching patterns so that half the time the transformer sees only half the input voltage (enabling ZVS and wide voltage tolerance)vbn.aau.dkvbn.aau.dk. The paper also emphasizes keeping switch currents balanced to equalize losses and thermal stressvbn.aau.dk.

Earlier T-type DAB implementations (e.g. with half-bridges on each leg) were limited by high current stress on switchesvbn.aau.dk. For instance, Wang *et al.* review shows half-bridge T-type DABs have twice the current stress of full-bridges in equivalent conditionsvbn.aau.dk. The modern full-bridge T-type overcomes this. In summary, literature suggests that combining full-bridge DAB isolation with a T-type modulation on one side could leverage wide voltage handling and soft-switching benefitsvbn.aau.dkvbn.aau.dk.

Control Limitations: Most DAB control uses phase-shift between square-wave bridges. Standard microcontroller ePWM modules only produce fixed-frequency PWM (often 50% duty for square wave) with limited flexibility. This conventional PWM cannot easily generate multi-level or asymmetric waveforms. Thus, advanced modulation schemes (like the two-pattern T-type wave) are not directly achievable with basic ePWM settings. Consequently, the current 50%-duty square drive may force some switches out of soft-switching (leading to losses) and cannot exploit the full potential of a T-type topology. In practice we see one bridge not contributing properly, suggesting the standard ePWM approach is insufficient. This motivates the move to a quasi-square (two-step) waveform on the input side, as in the reference converter.

Simulation Results:

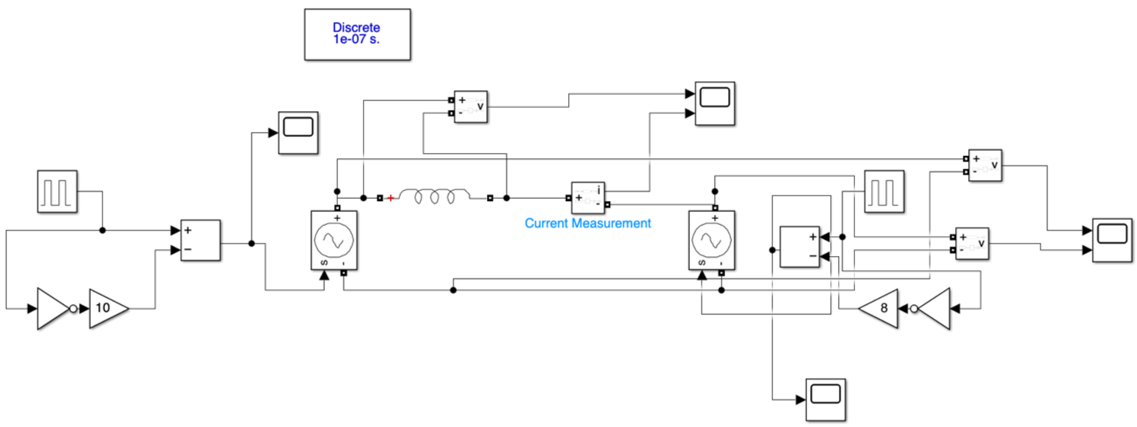

Figure 3. Equivalent circuit of both the bridges without transformer

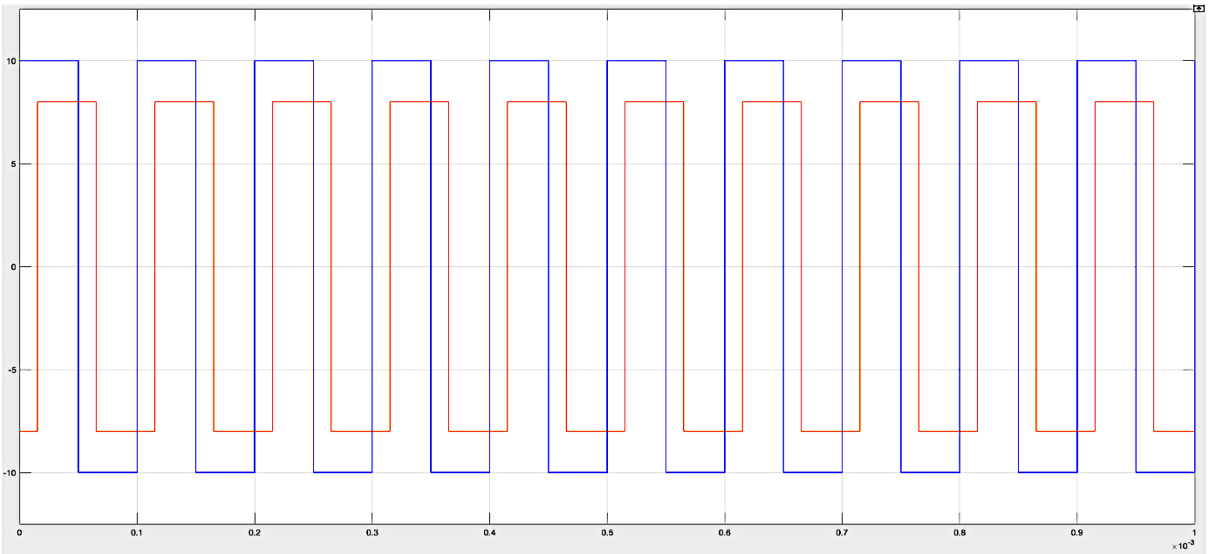

Figure 4. Primary and Secondary Voltages

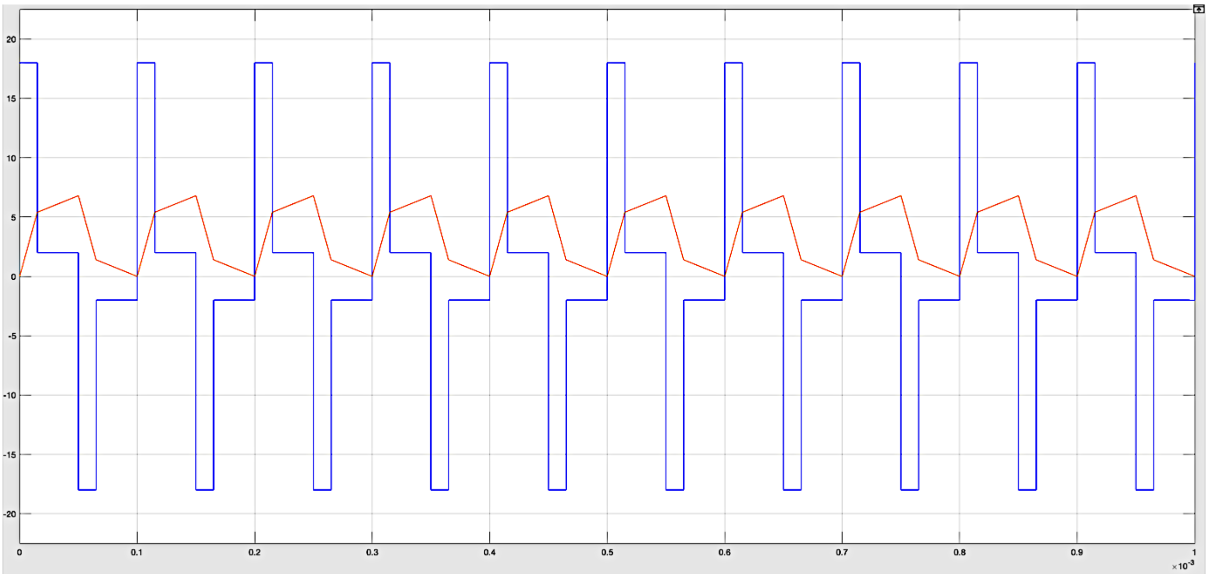

Figure 5. Inductor Voltage and Current

Using quasi-square wave input:

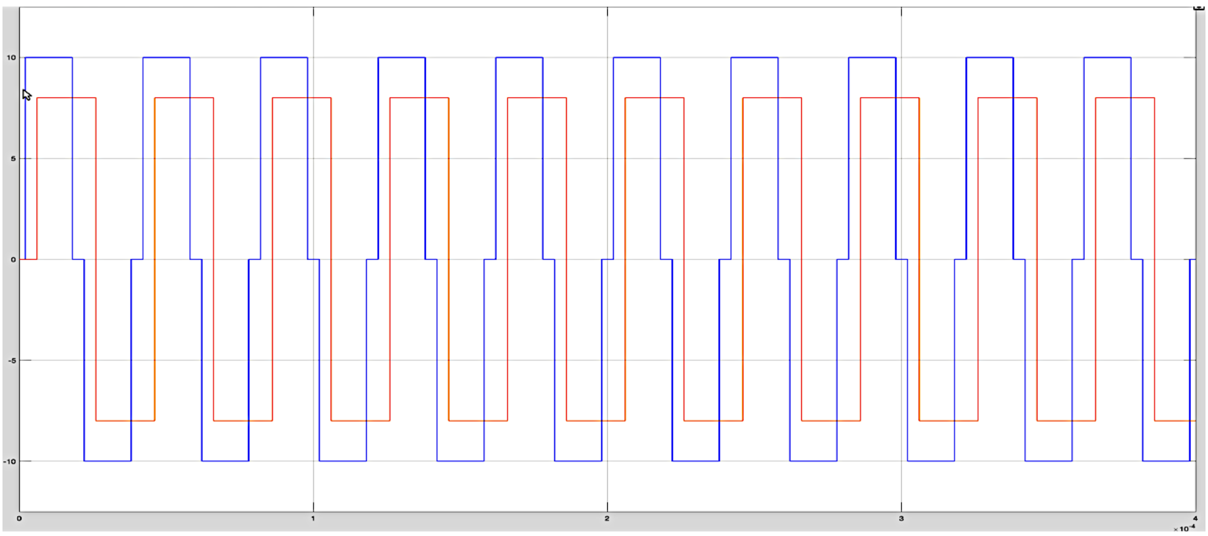

Figure 6. Primary and Secondary Voltages

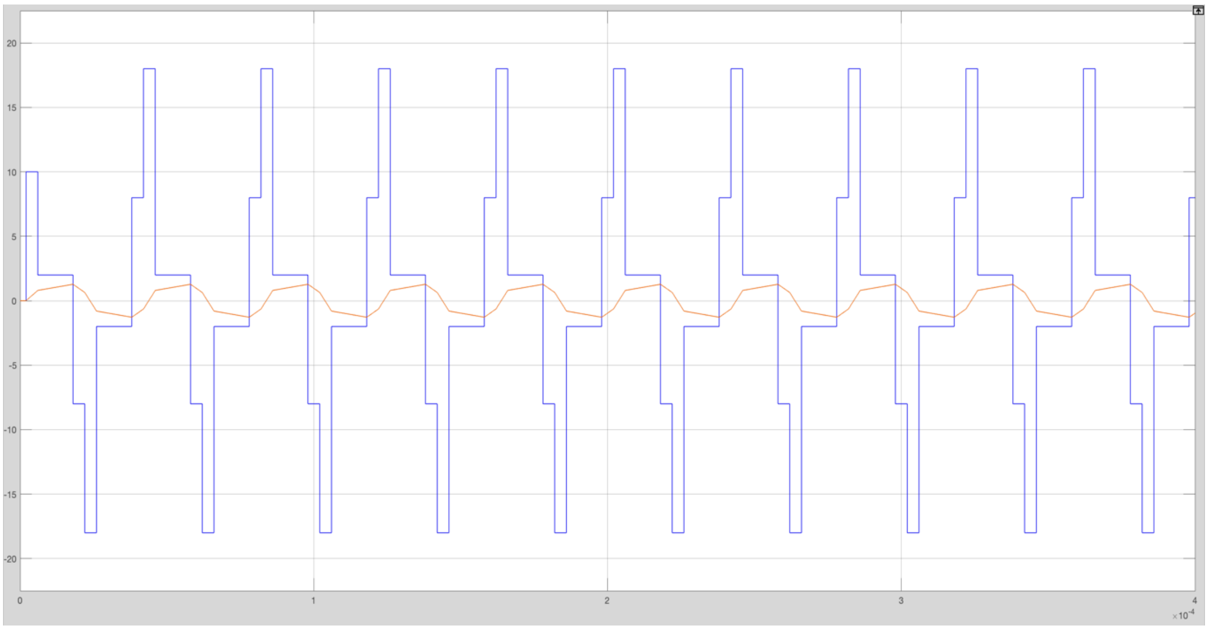

Figure 7. Inductor Voltage and Current

Hardware Implementation:

The current converter hardware is outlined in the block diagram below:

- **AC Input and Rectifier:** Single-phase AC from the mains is adjusted via a variac, then fed to an H-bridge full-wave rectifier to produce a DC bus. Two split capacitors provide a mid-point, but initially only fixed rails are used.
- **C2000 Microcontroller and pulse generation:** Launchpad F28379D produces 2 phase shifted 10kHz 3.3v gating pulses for the IGBT switches with 50% duty ratio for a square wave output at the inverting point.
- **Level shifter:** which shifts 3.3v pulse from c2000 to 5v pulses to drive the gate driver circuits.
- **Gate driver circuits:** Semikron Skyper 32 pro is used to drive the switches.
- **DAB Half-Bridge Converters:** The DC bus feeds two identical half-bridge inverters (primary and secondary side). Each half-bridge consists of two IGBTs and a DC-link midpoint. The microcontroller's ePWM modules switch each bridge at a set frequency (e.g., 10 kHz) and 50% duty, producing square-wave voltages on the primary (primary side) and secondary (load side) of the HF transformer.
- **High-Frequency Transformer:** A high-frequency isolation transformer with known turns ratio (2:1) sits between the two bridges. Its primary sees the differential of the primary bridge voltages, and its secondary is connected to a load.
- **Secondary Rectifier/Load:** The transformer secondary feeds a full-wave rectifier which drives the resistive test load (simulating a battery).

Experimental Parameters:

Operating frequency	10kHz
Transformer rating	100:50V, 500W, 10kHz
External inductance	100uH
Battery voltage	12V
Power Source	0-230V 1-ϕ Variac
Microcontroller	C2000 F28379D
Gate Drivers	Semikron Skyper 32 Pro
Switches	Semikron SKM75GB12T4

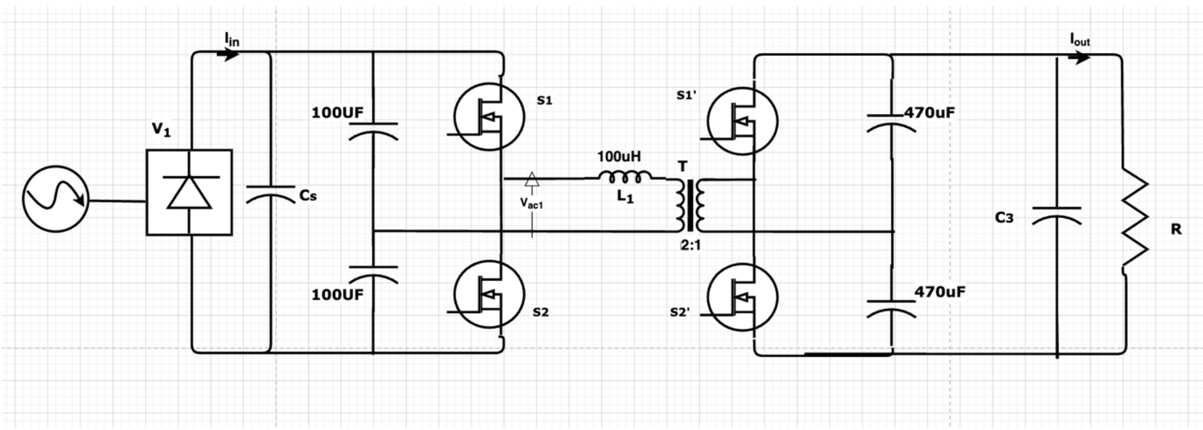

Figure 8. Circuit Diagram of Half-Bridge DAB

The operating principle with square-wave control is as follows. Each half-bridge is driven by complementary PWM signals (each at 50% duty) so that each bridge outputs a square voltage (Vab for primary, Vcd for secondary) alternating between +Vin/2 and –Vin/2. In normal bidirectional DAB operation, these square-wave voltages overlap in time, and power flows according to their phase shift. For example, if the primary waveform leads the secondary, energy flows from primary to secondary. In this implementation both bridges were driven at fixed 36° phase shift using the microcontroller's PWM timers.

Experimental Results:

Preliminary tests focus on verifying waveforms and identifying the fault. Key observations (placeholders):

- **Waveforms:** The oscilloscope captures show the expected ±Vin/2 square-wave voltages on both primary and secondary bridges. For example, Fig. shows the primary bridge midpoint voltage and secondary bridge midpoint voltage vs. time at 10 kHz switching.

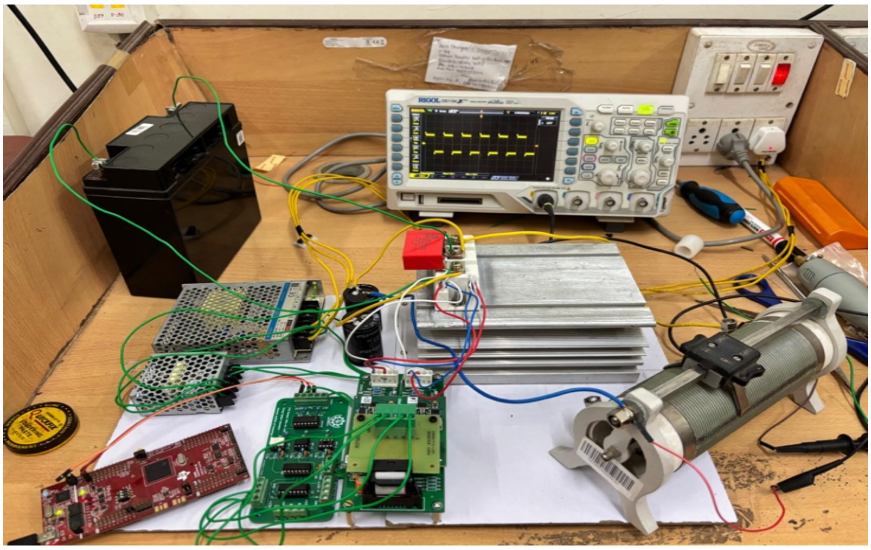

Figure 9. Experimental Setup for half-bridge inverter

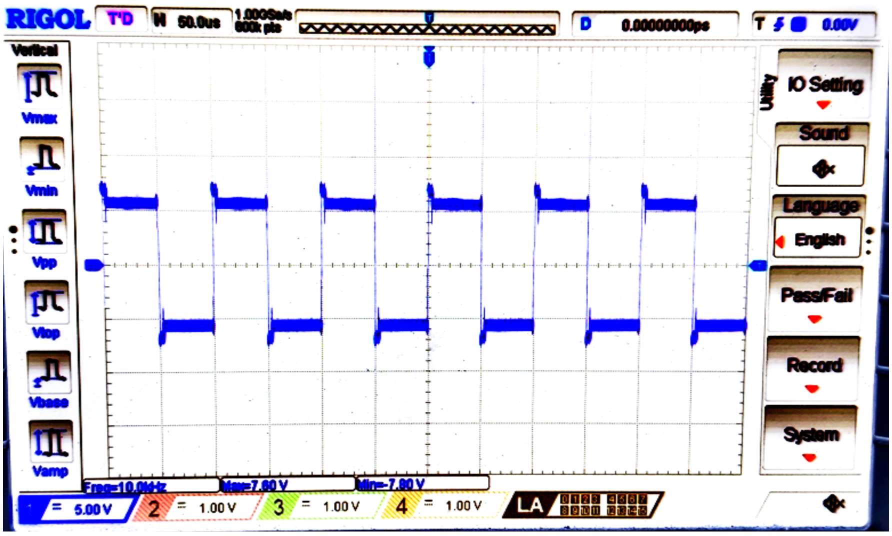

Figure 10. Output Voltage across a resistor

Final Setup:

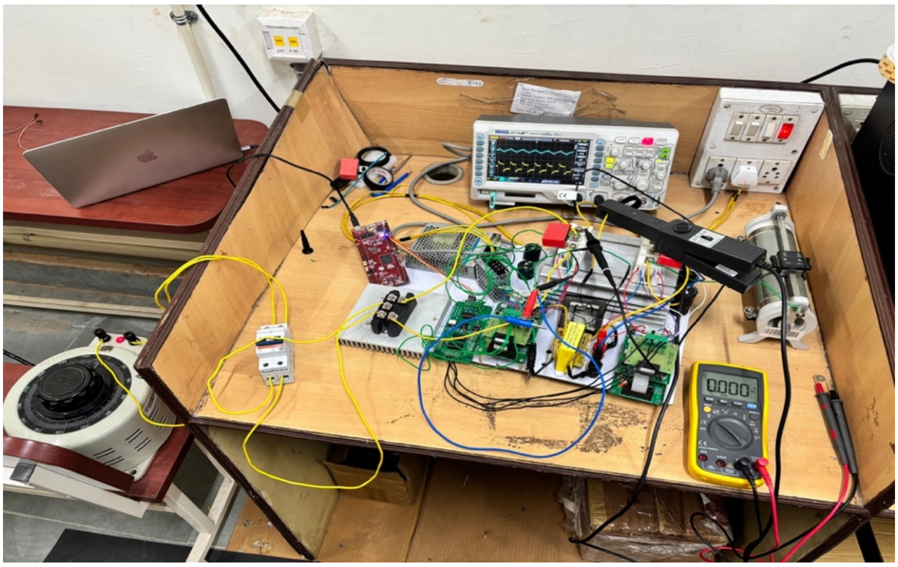

Figure 11. Final Experimental Setup

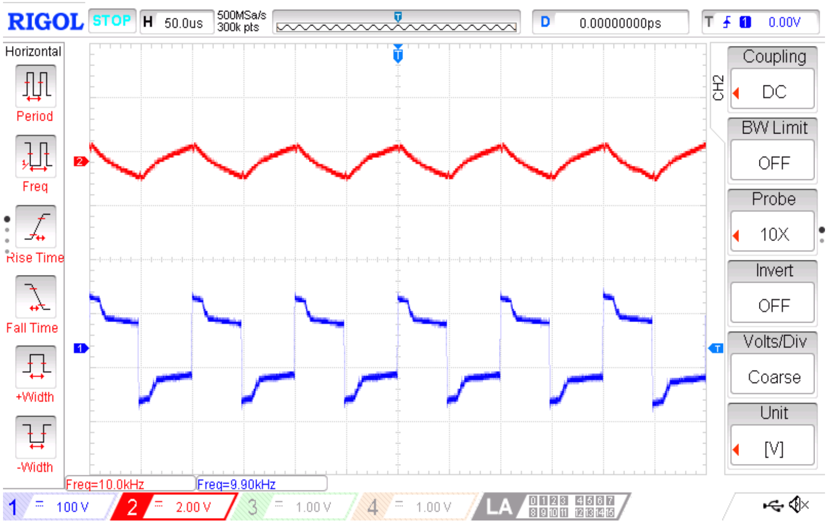

Figure 12. Inductor current and voltage

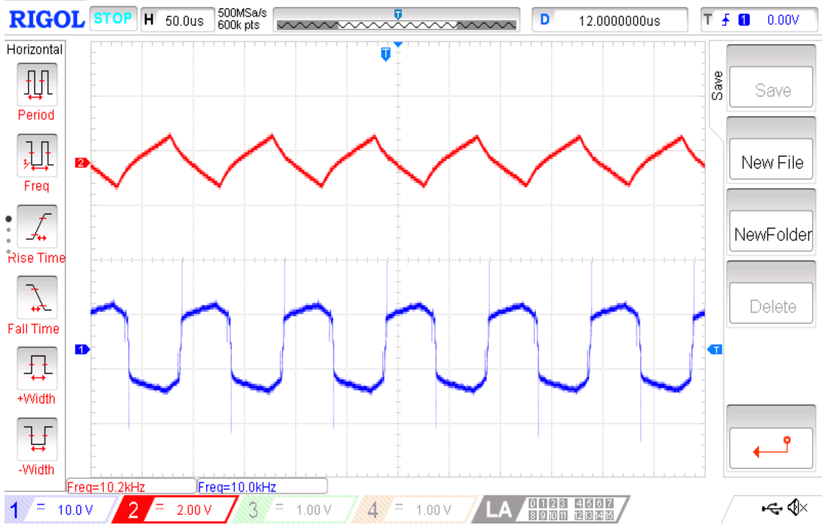

Figure 13. Inductor current and sec side input volt

Progress till now:

- C2000 microcontroller is programmed to produce 2 pulse trains with shifted phase angles.
- The level shifter works perfectly fine.
- The first inverting half bridges shows desired results.
- The made inductance is of the desired value(100uH).
- The square wave reaches till the input of the load-side rectifier.
- The 2nd bright works fine as an inverter but doesn't as a rectifier.

Overall, roughly 80% of the expected functionality is achieved: the bridges switch and the transformer magnetizes, but insufficient current is delivered to the load. Further analysis and hardware tuning (e.g. check gate drive timing and deadtime) will be needed.

Hardware Specifications: Input AC: variable 230 V RMS, Switching frequency: =10 kHz. Transformer turns ratio: 2:1. Bridge devices: IGBTs. DC link caps: 0.02 µF.

Future Work

To address the limitations and realize full functionality, the following steps are planned:

1. **Fixing the secondary side bridge:** To produce dc putout and replace the resistor with a battery for actual usage.
2. **Implement T-Type Quasi-Square Modulation:** Modify the control of the *input* half-bridge (primary side) to produce a three-level (quasi-square) waveform. In practice, this means driving the bridge such that for a portion of each cycle it outputs +Vin/2 and –Vin/2, and for another portion it outputs 0 V (using the split DC link). This effectively creates two voltage levels (±Vin/2 and 0) on the primary, as in the T-type converter of Liu *et al.*vbn.aau.dkvbn.aau.dk. We will develop a PWM sequence (e.g. three-step pulses) to realize this pattern on the C2000.

Conclusion

This report detailed the implementation of a dual active bridge DC-DC converter for battery charging. We have outlined the hardware architecture (Variac + H-bridge rectifier, two half-bridge inverters, transformer, and load) and the initial results of our square-wave drive tests. While most hardware functions, one half-bridge currently fails to contribute, resulting in low output current. The literature review showed that T-type (three-level) modulation can extend soft-switching and voltage range by effectively halving the applied transformer voltage in one modevbn.aau.dkvbn.aau.dk. As future work, we will implement a T-type quasi-square waveform on the input bridge, which is expected to improve power delivery and enable both bridges to contribute fully. Further simulation and closed-loop control design will follow. With these enhancements, the converter should achieve reliable battery charging performance as intended.

References

1. D. Liu, Y. Wang, F. Deng, Q. Zhang, and Z. Chen, "Zero-Voltage Switching Full-Bridge T-type DC/DC Converter with Wide Input Voltage Range and Balanced Switch Currents," *IEEE Trans. Power Electron.*, vol. 33, no. 12, pp. 10449–10466, Dec. 2018.
2. J. Rajender, M. Dubey, Y. Kumar, B. Somanna, M. Alshareef, B. Namomsa, S. Ghoneim, and S. A. M. Abdelwahab, "Design and analysis of a high-efficiency bi-directional DAB converter for EV charging," *Sci. Rep.*, vol. 14, Art. 23764, 2024.
3. S. Jain and R. Ayyanar, "PWM control of dual active bridge: comprehensive analysis and experimental verification," *IEEE Trans. Power Electron.*, vol. 26, no. 4, pp. 1215–1227, Apr. 2011.