Multi-Stage Power Conversion Systems for Next-Generation Energy Storage

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Organization: 08814 (Power Electronics and Power Conversion Systems)

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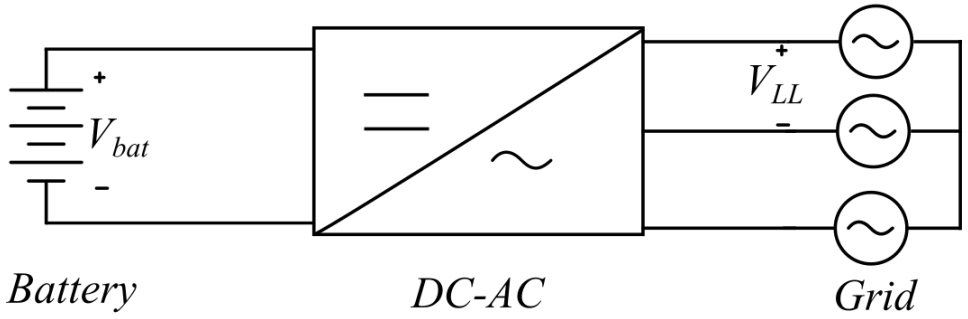
SAND NO. SAND2021-13030 C

Power Conversion Systems (PCS) for Energy Storage

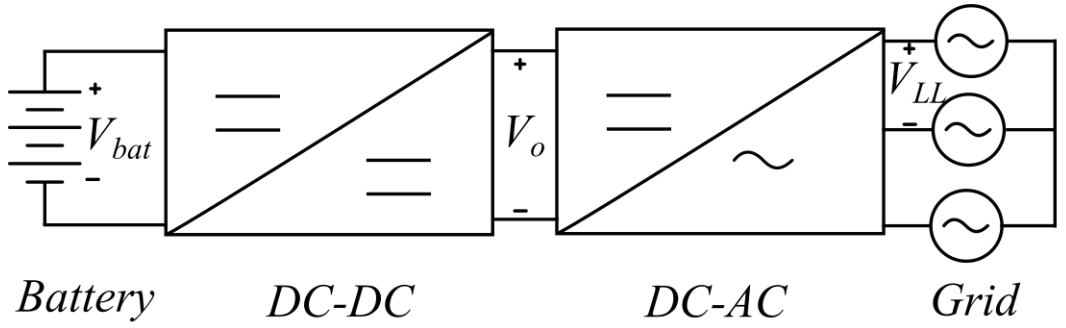


Single-stage PCS Architecture

- Simplest interface strategy where all PCS functions are performed by a single DC-AC converter, which generally is a voltage source inverter (VSI)
- To avoid grid voltage distortion, the constraint $V_{bat,min} \geq \sqrt{2}V_{LL}$ needs to be maintained
- Significant overdesign of the DC-AC converter is required
- Limited to 480 V system, not suited for a direct connection to a medium voltage (MV) grid

Drivers for Multi-Stage PCS

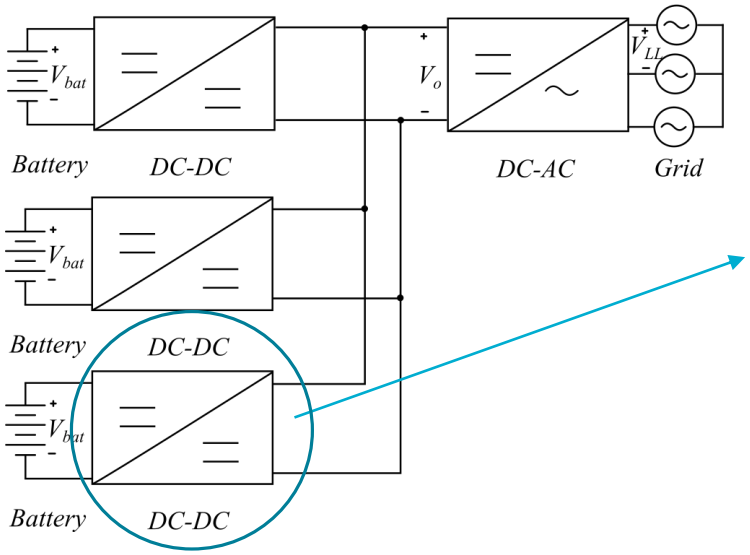
- Energy focused application for long duration (30 years)
- High Reliability and Efficiency
- Scalability of the power converter topology



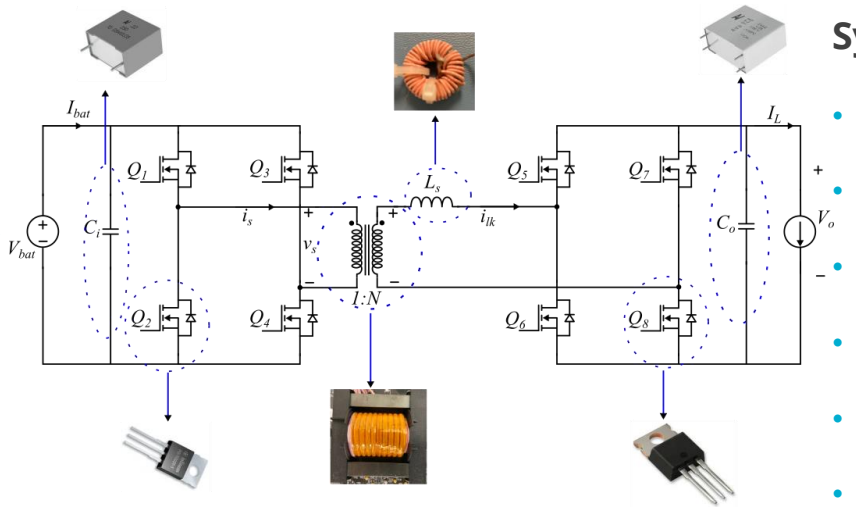
Multi-stage PCS Architecture

- Separate DC-DC and DC-AC converters are used to interface the low voltage energy storage to the AC grid
- DC-DC converter decouples the inverter DC-link voltage (V_o) from the charge-dependent battery voltage (V_{bat}) and also provides voltage boosting
- Low voltage battery systems can be designed with lower balancing loss and higher reliability
- Intermediate DC-link provides a point of accumulation for multiple DC sources to achieve greater flexibility in system design
- Modular design strategy results in higher power density, higher efficiency, reduced battery current ripple, lower component stresses

Modular Parallel Connected Power Conversion System



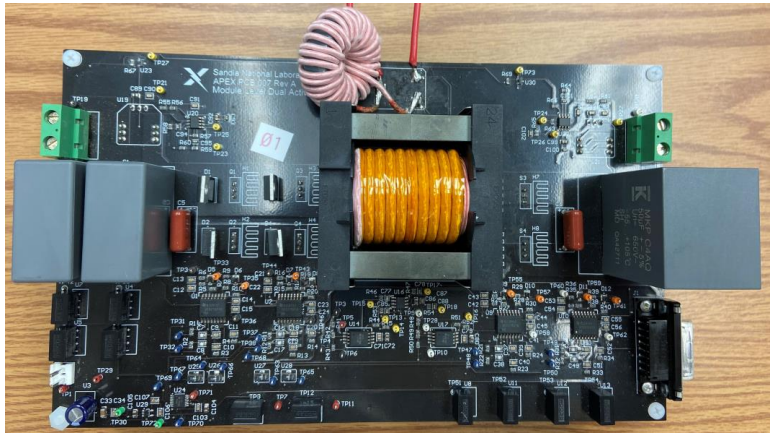
Multi-Stage Parallel PCS



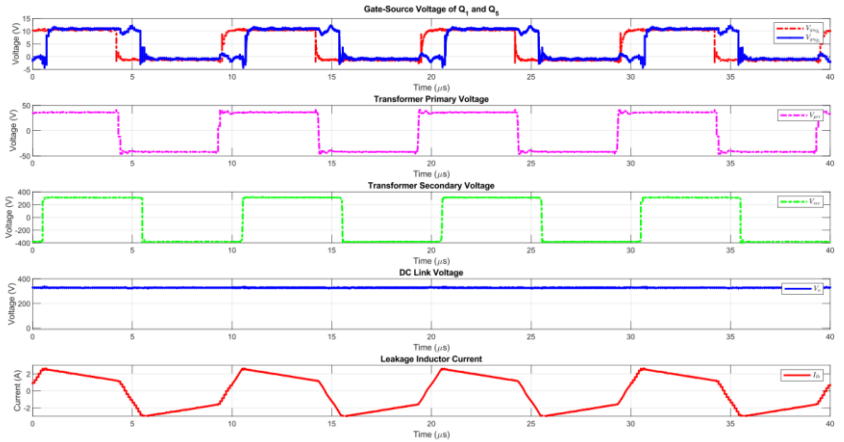
Dual Active Bridge (DAB) Converter

System Specification

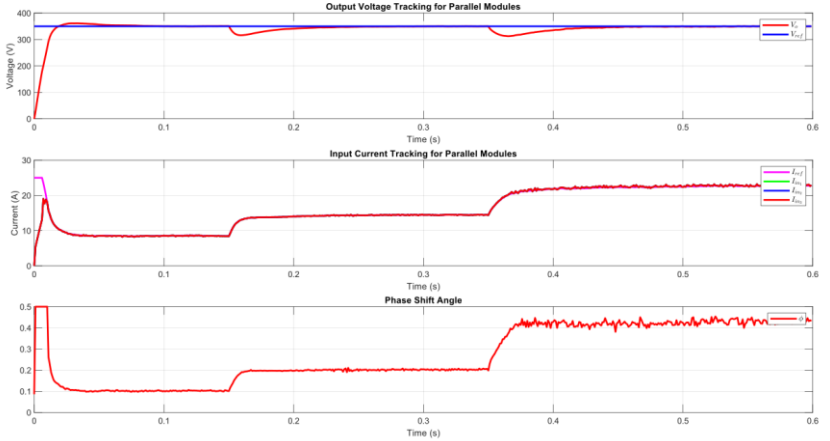
- Battery Voltage: $30\ V \leq V_{bat} \leq 42\ V$
- DC Link Voltage: $V_o = 350\ V$
- Rated Power: $P_o = 500\ W$
- Battery Current: $-11.9\ A \leq I_{bat} \leq 16.7\ A$
- Switching Frequency: $f_s = 100\ kHz$
- Three DAB DC-DC converters are connected in parallel to demonstrate scalability and higher reliability of the PCS



PCB Implementation of DAB



Open Loop Experimental Results at Rated Power



Closed Loop Simulation Results for Parallel Modules

K_{pi}=0.07, K_{ii}=7347, K_{pv}=0.58, K_{iv}=25.2

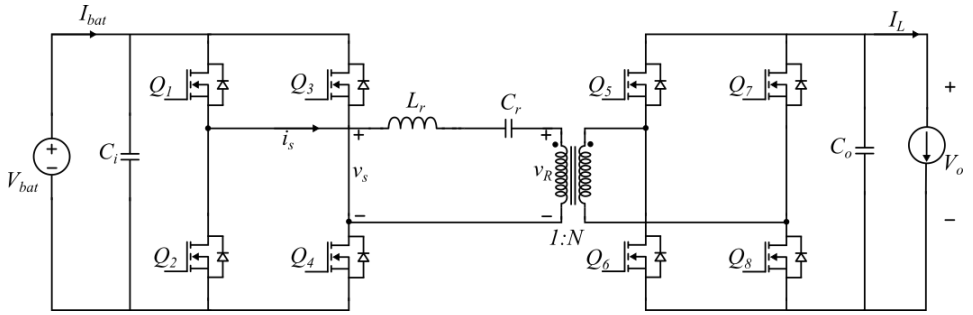
Performance Optimization with Resonant Power Conversion

Operational Issues with DAB

- Narrow soft-switching range of single phase-shift modulated DAB leads to higher losses at partial load operation
- Discontinuous input current leads to higher filtering requirement

Why Resonant Converter?

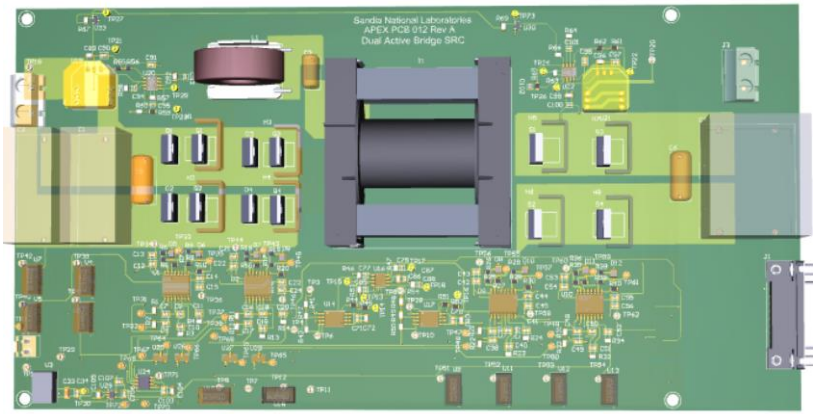
- ❑ High switching frequency of operation with inherent soft-switching
- ❑ Less susceptibility to parasitic components
- ❑ Lower component stress with optimized tank design
- ❑ Higher operating efficiency over the designed load range realizes lower cost over the lifetime



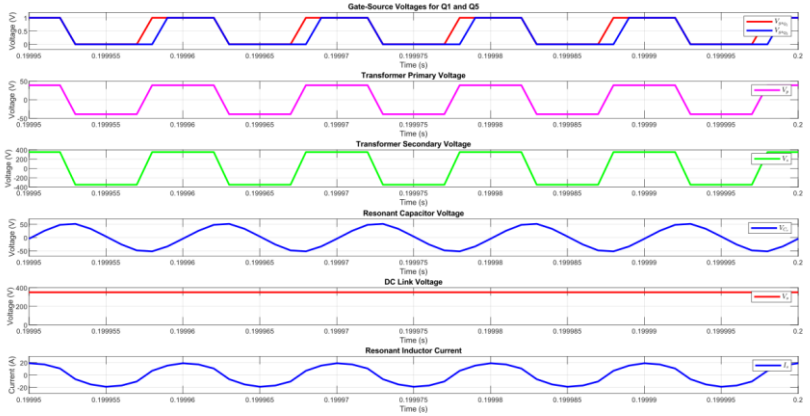
Dual Active Bridge Series Resonant Converter (DABSRC)

Conclusions and Future Work

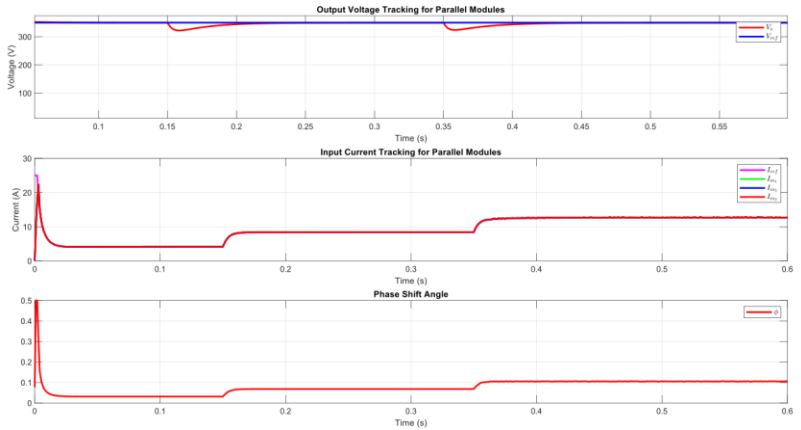
- ➢ The parallel operation of DABSRC results in lower input current for the rated power operation
- ➢ Current stress on the transformer is reduced
- ➢ Hardware Implementation is in progress



3D view of DABSRC PCB



Rated Power Operation of DABSRC



Closed Loop Control of Parallel Modules
K_{pi}=0.07, K_{ii}=7347, K_{pv}=0.58, K_{iv}=25.2

Acknowledgement

We would like to thank Dr. Imre Gyuk and the US DOE Office of Electricity for supporting this work.