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TEXAS
The University of Texas at Austin

SPEC
Semiconductor Power Electronics Center

Sandia National Laboratories

LOW VOLTAGE AND HIGH CURRENT BIDIRECTIONAL CONVERTER FOR GRID-TIED ENERGY STORAGE SYSTEM WITH BATTERY MANAGEMENT SYSTEM

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PRESENTATION ID #804

Semiconductor Power Electronics Center
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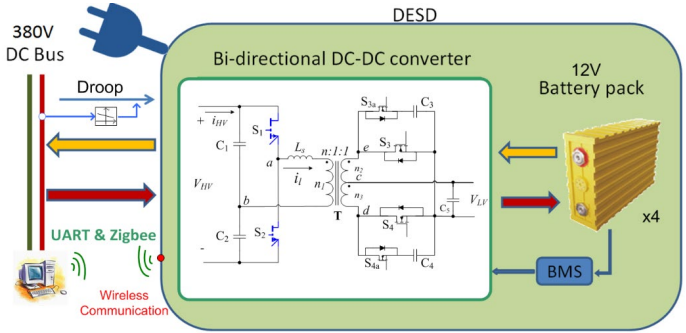
- Previous SPEC Work Review on Battery Energy Storage System(BESS)

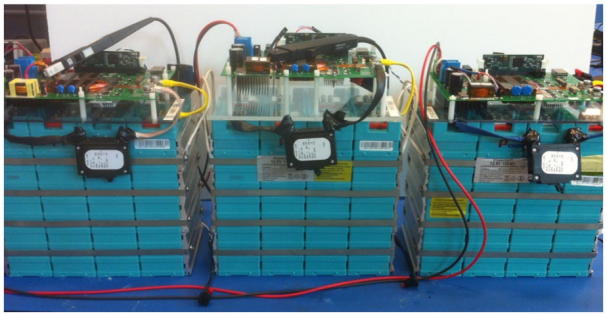
- Proposed 12V Series Resonant Dual Active Bridge(SR-DAB)
  - Single Stage Topology Review
  - SR-DAB Overview
  - SR-DAB Operation Principle & Optimization
  - Hardware Specification
  - Experiment Verification

- Battery Management System(BMS) Integration on DSP
  - BMS Constituents
  - System Structure

- Summary & Future Work

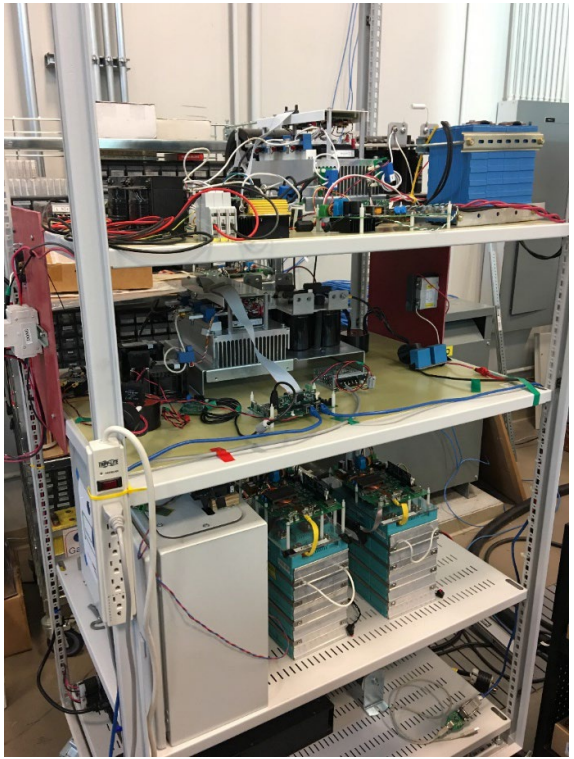
800W 380Vdc-12Vdc bi-directional converter (2015)



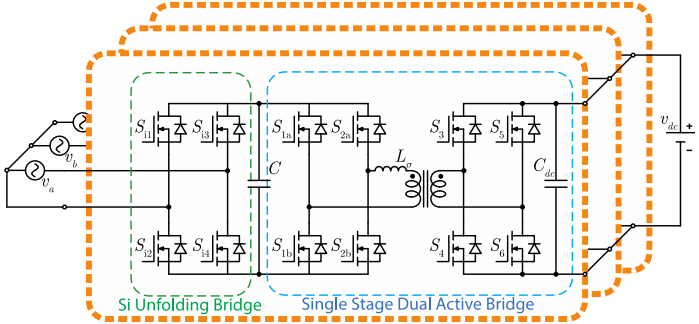


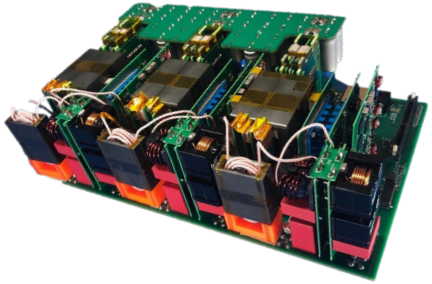
800W DC/DC, natural cooling
98.3% peak efficiency
30W/in^3

240Vac-380Vdc DC Micro Grid (2015)



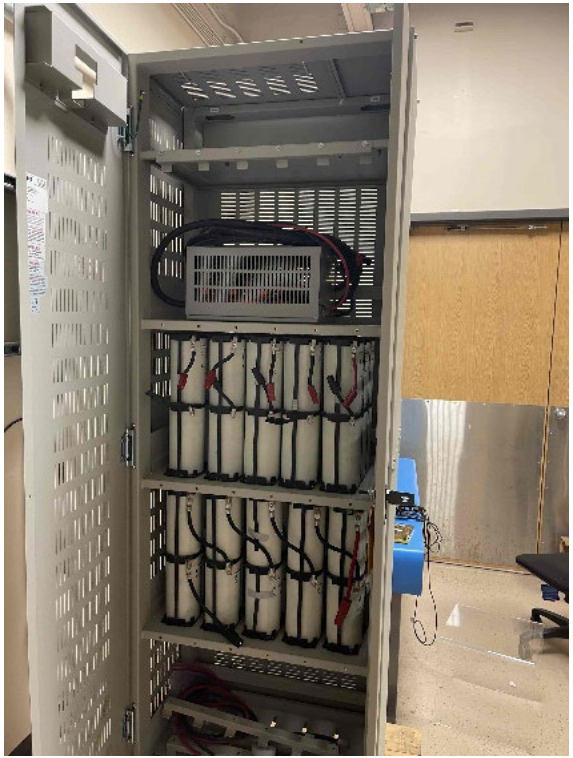
10 kW 208Vac to 48Vdc bi-directional charger (2021)





10kW AC/DC, forced air cooling
97% peak efficiency
50W/in^3

208Vac 3-phase Energy Storage System (2021)



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T. Chen, R. Yu and A. Q. Huang, "A Bidirectional Isolated Dual-Phase-Shift Variable-Frequency Series Resonant Dual-Active-Bridge GaN AC-DC Converter," in *IEEE Transactions on Industrial Electronics*, 2022, (Early Access)

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T. Chen, R. Yu, Q. Ma, X. Zhao and A. Q. Huang, "Optimal Control Scheme for Single-Stage Dual-Active-Bridge AC-DC Converter," 2018 IEEE Energy Conversion Congress and Exposition (ECCE), 2018, pp. 2860-2864

T. Chen, R. Yu, Q. Huang and A. Q. Huang, "A single-stage bidirectional dual-active-bridge AC-DC converter based on enhancement mode GaN power transistor," 2018 IEEE Applied Power Electronics Conference and Exposition (APEC), 2018

F. Xue, R. Yu and A. Q. Huang, "Design considerations of an isolated GaN bidirectional dc-dc converter," 2016 IEEE Energy Conversion Congress and Exposition (ECCE), 2016, pp. 1-7

Proposed a single stage AC-DC converter for 12V battery system

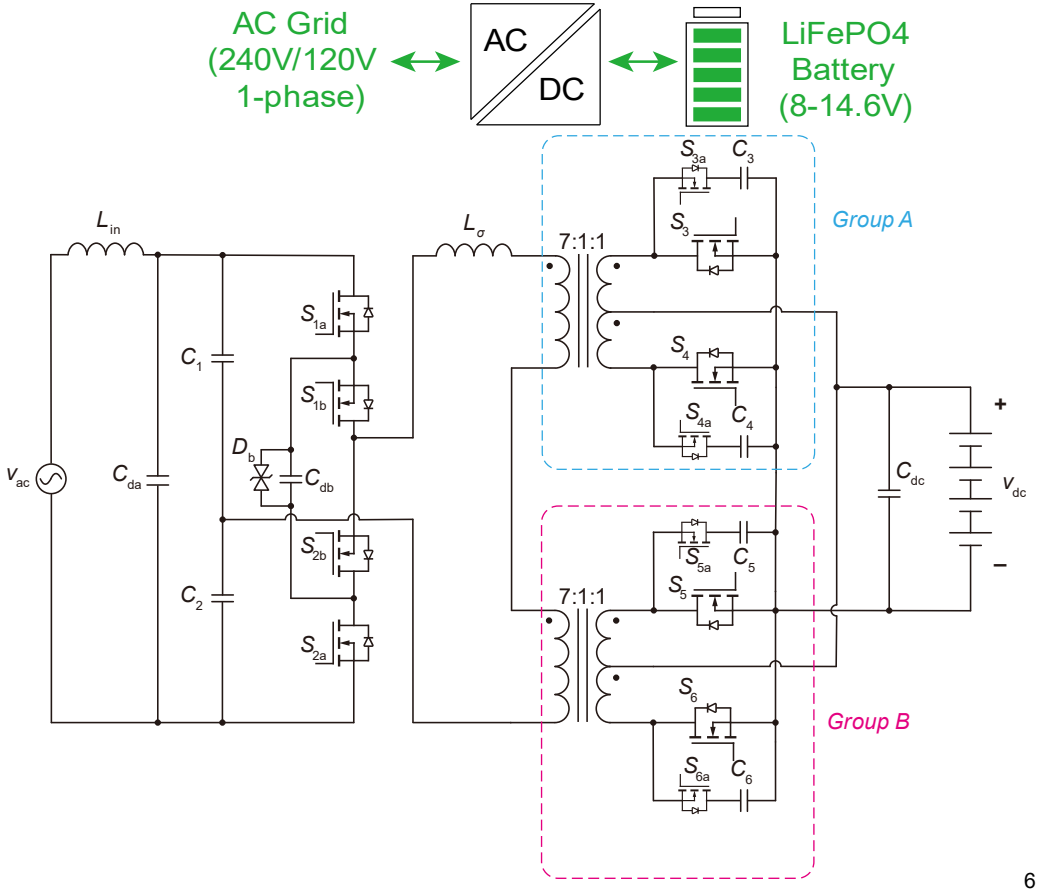
Novel 12V Series-Resonant Dual Active Bridge (SR-DAB) Topology

Pros:

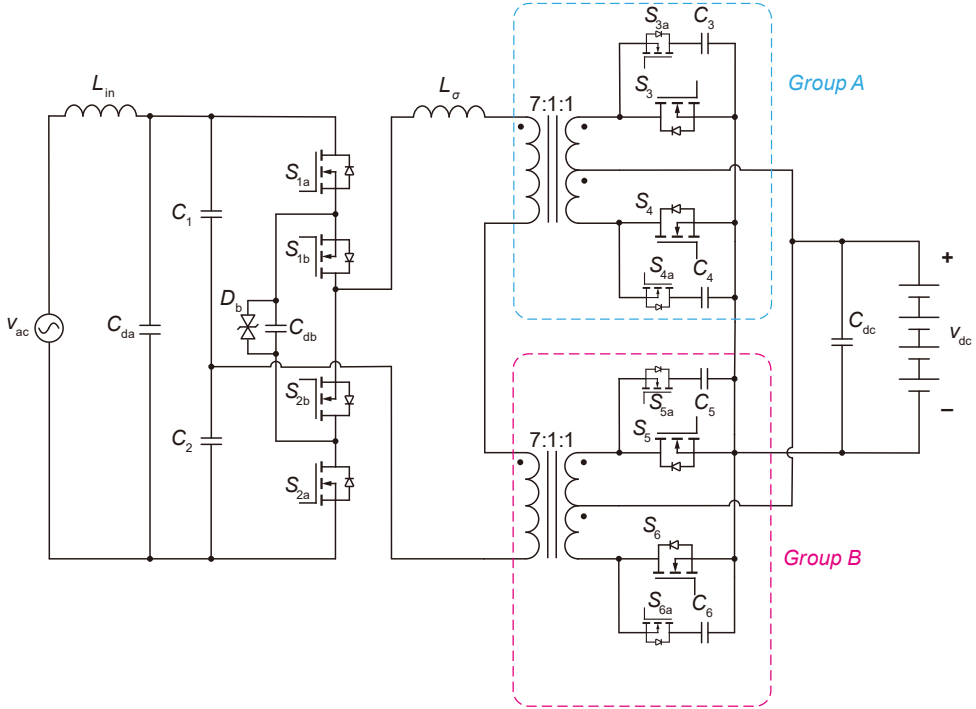
- Single stage bi-directional power delivering.
- Lower RMS current & Switching current for transistors.
- In need of less energy buffer capacitor.
- No inrush current issue due to smaller AC cap.
- Center-tap transformer double current with half of the transistor number.
- PFC & Full Range ZVS guaranteed.

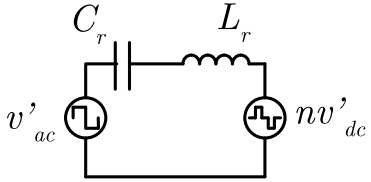
Cons:

- Complex AC/DC control.

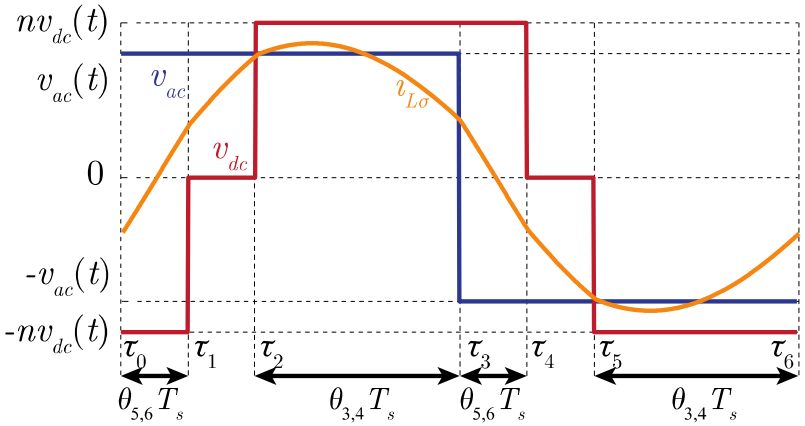


SR-DAB Operation Principle





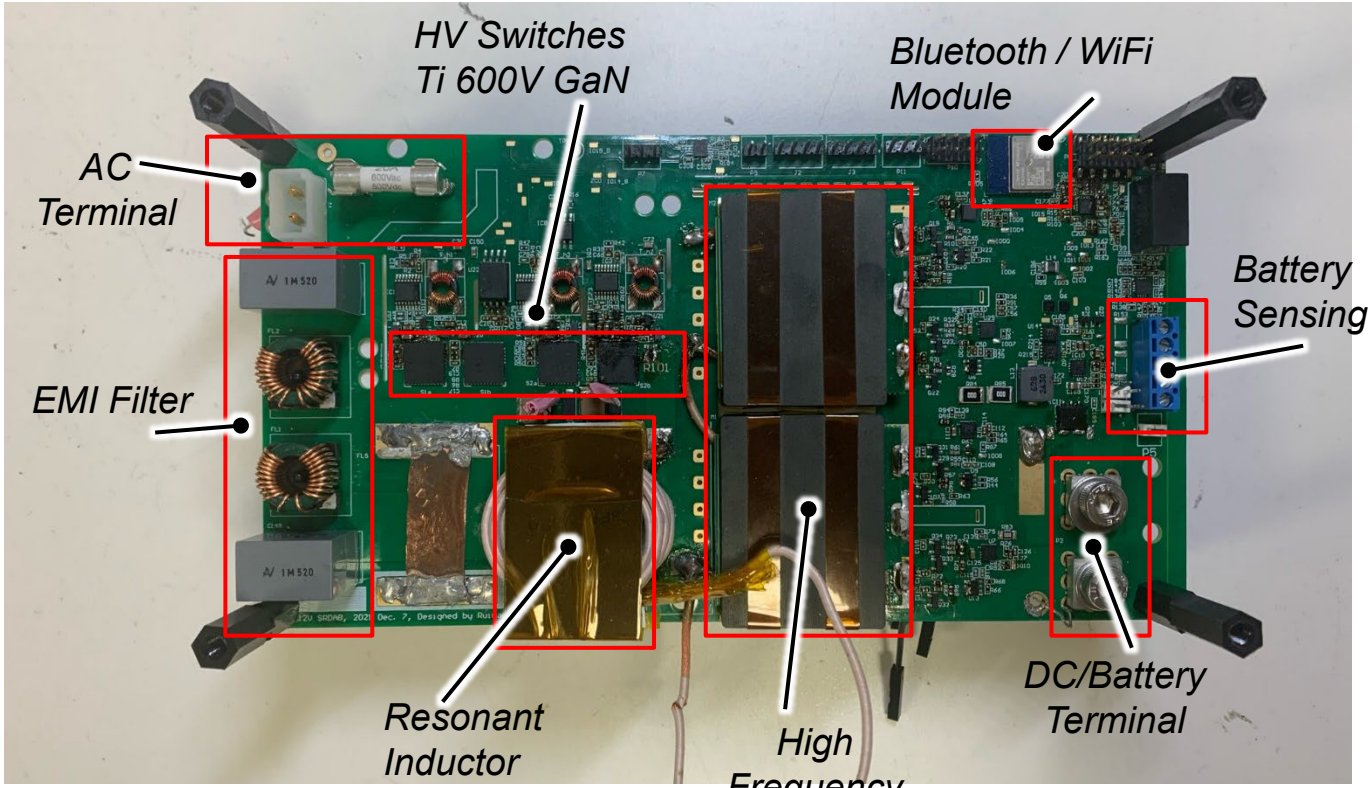
Simplified Representation @ single stage SR-DAB



Operation waveform @ Charge state

- 600V 50mΩ GaN enabled AC Switches on HV side, center-tap circuit with Si on LV side.
- Have a resonant LC tank.
- Variable 140kHz-350kHz switching frequency for size reduction.

AC-DC Converter + BMS + Wireless IoT= One Board

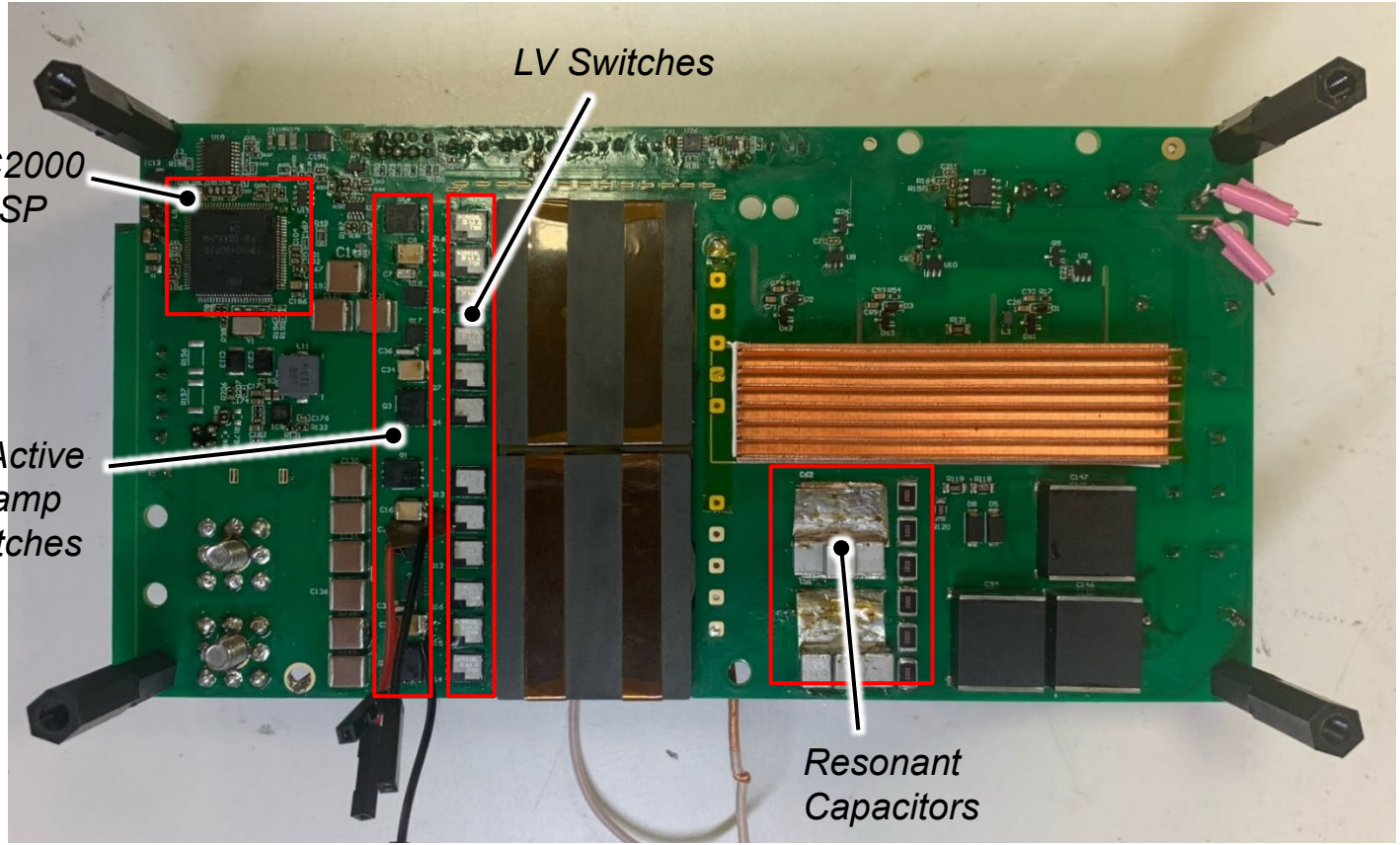


180*90*20mm^3 or 7.08*3.54*0.79inch^3

Specification:

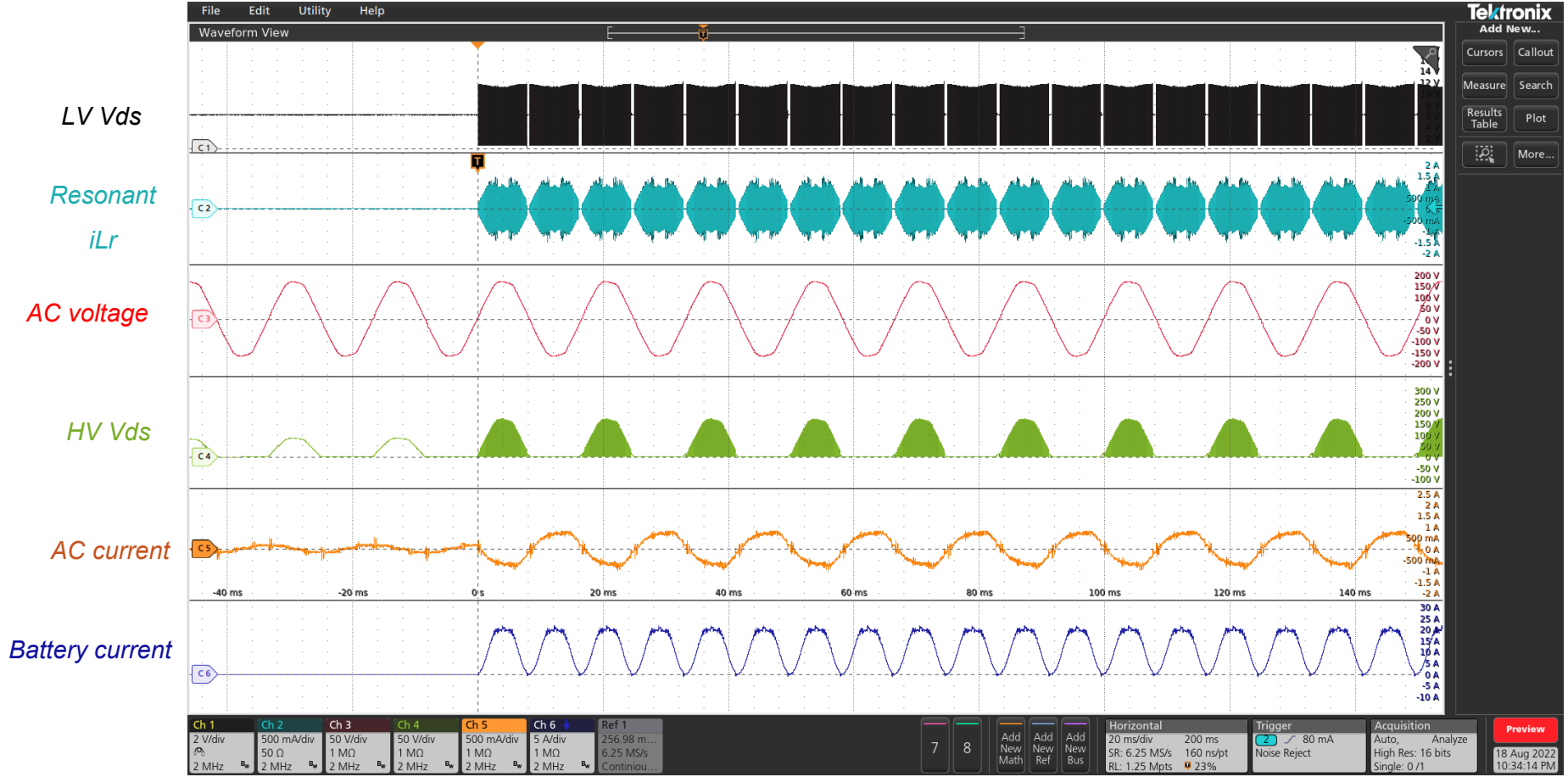
600W AC/DC
Natural cooling
97% peak efficiency
30W/in^3

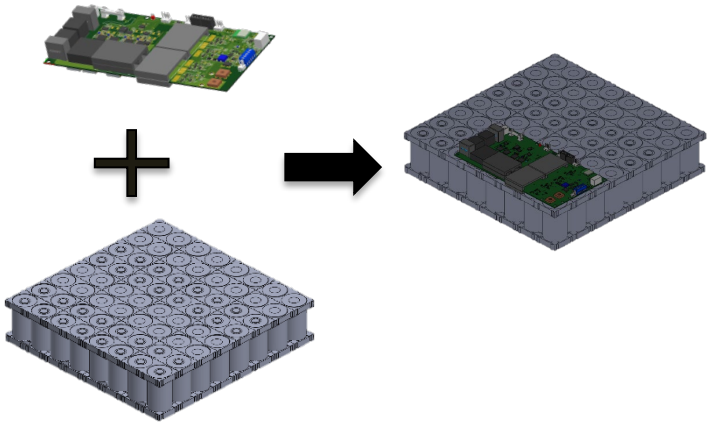
AC-DC Converter + BMS + Wireless IoT= One Board

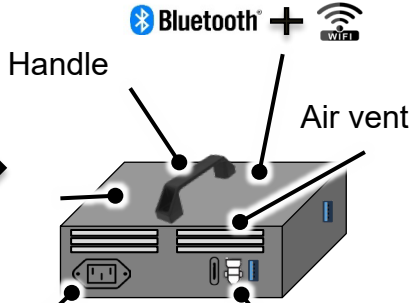


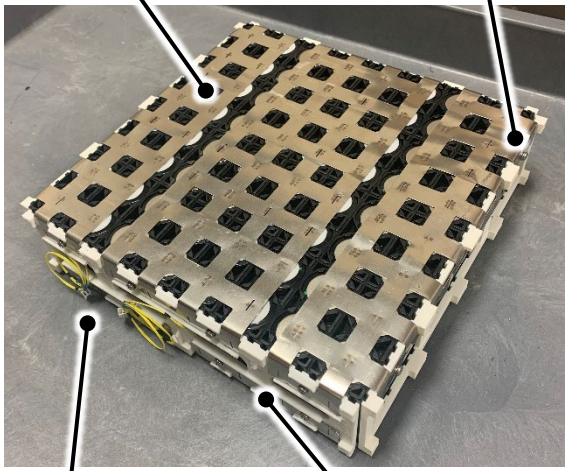
180*90*20mm^3 or 7.08*3.54*0.79inch^3

Experiment Verification





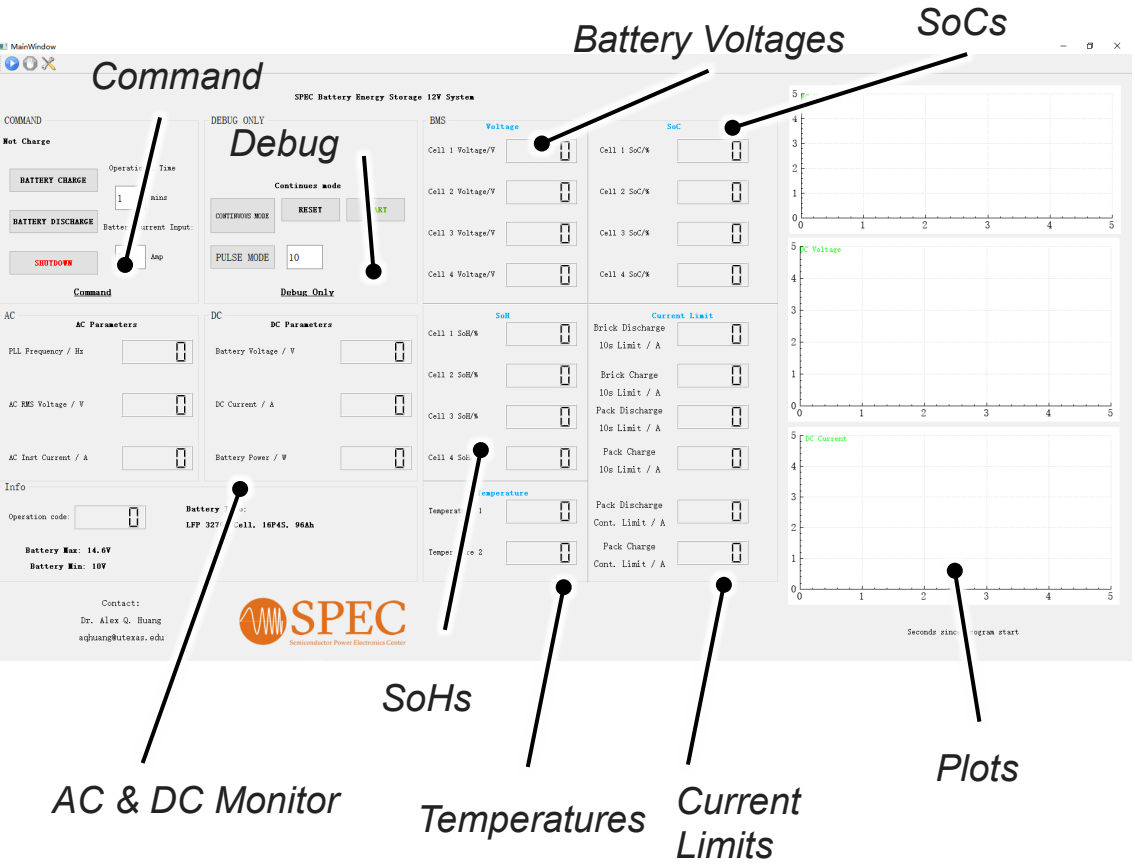




Proposed BESS Unit Mechanical Model

Operation Verification on Laptop

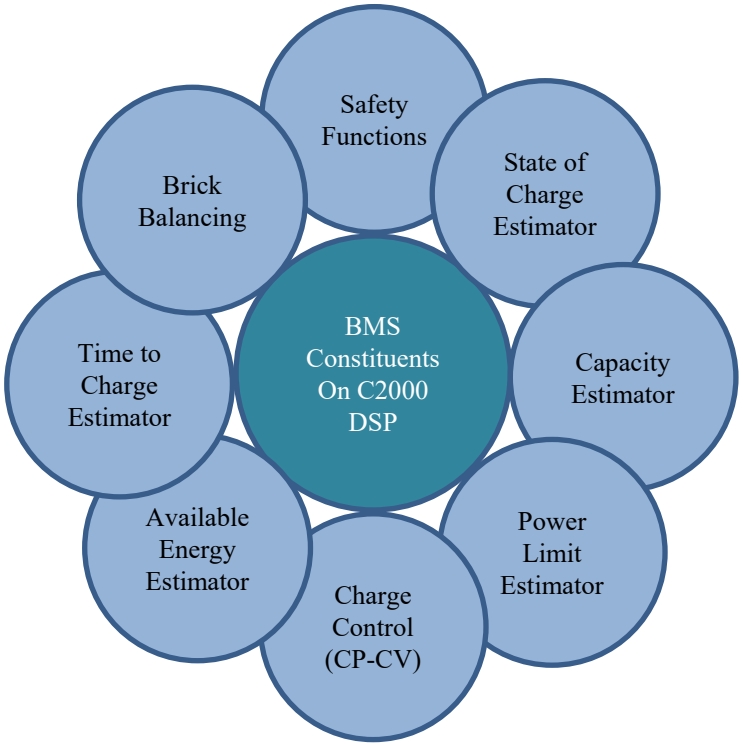
Wireless Communication Interface



Test Setup

- User Interface(UI) can used to control, record data and BMS monitoring.
- Bluetooth wireless protocol enables PC/Android wireless converter control & BMS.
- WiFi protocol for potential IoT cloud control and online data storage.

BMS Implementation



1. Safety Functions
- Tiered OV/UV, OT/UT
- Current limit enforcement / overcurrent monitoring
- Charge inhibition post deep discharge / recovery through trickle charge
- EoL control – charge voltage reduction / charge inhibition

2. SoC Estimation
- EKF based, using a 1-RC ECM. Target accuracy: +/- 3%

3. SoH Estimation
- TBD. Need non-volatile memory. Target accuracy: +/- 3%

4. Charge / discharge current limit computation (continuous + peak)
- Online, terminal voltage based computations + pre-computed LUTs

5. Available Energy Estimation
- TBD. Target accuracy: +/- 5%

6. Brick Balancing
- Passive, top of charge balancing, terminal voltage based

7. Time to Charge Estimation
- TBD

Summary:

- Designed the 600W 240Vac/12Vdc or 120Vac/6Vdc prototype based on a novel Series Resonant Dual Active Bridge (SR-DAB) circuit topology. The prototype has been built and tested over the grid connection and a LFP battery pack.
- The prototype functions are validated including converter operation control, BMS calculation & Wireless communication.

Hardware:

- SR-DAB single stage topology is developed and validated for achieving PFC & ZVS soft switching.
- A 0.986 power factor is achieved under >200W test condition with THDi lower than 5%.
- A complex AC-DC control with variant switching frequency is achieved.

Software:

- BMS real-time calculation on C2000 DSP is implemented, each iteration consumes lower than 35us.
- Wireless communication enables portable device monitoring & cloud monitoring.

Future Work:

- Close loop AC/DC control with Current Protection.
- Make BESS stackable, achieve de-centralized control.
- Optimize loss reduction & BMS accuracy.

THANK YOU FOR ATTENTION

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