Low Voltage and High Current Bidirectional Converter for Grid-tie Flow Battery Energy Storage System

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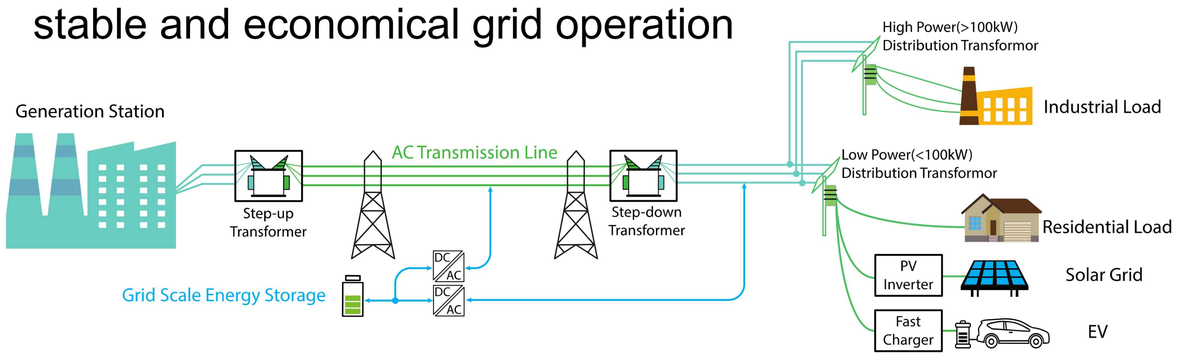
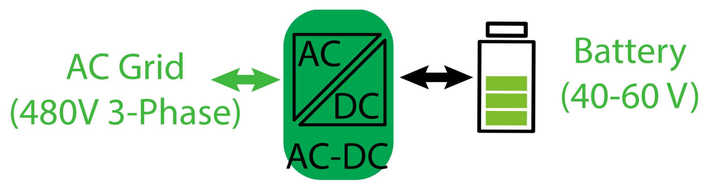
DOE ESS Program Mission

Conventional Power Grid
- Fossil fuel dominant generation
- Centralized generation resulting in inefficient T&D system

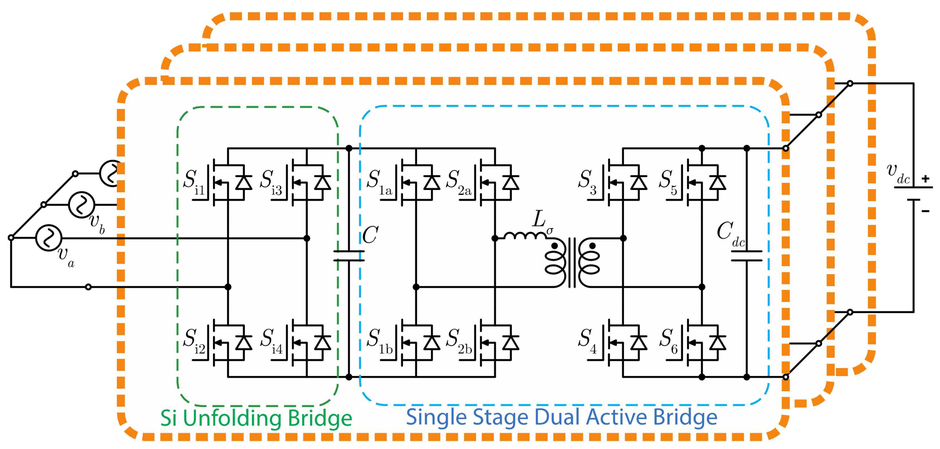
Future Power Grid
- Towards 100% renewable energy
- Dominated by distributed generation
- Centralized and distributed **Energy Storage** a necessity for stable and economical grid operation



Project Objective: 48V to Grid Flow Battery System



Project Goal and Specifications
- Battery Nominal Voltage: 48V
- AC Voltage: 480V/3-phase Y configuration
- Power Level: 10 kW



Advanced Single Stage AC/DC Topology with GaN Power Transistors and Soft Switching

Power Electronics requirement

Power Electronics Converter:
- Bidirectional power flow
- High efficiency and high power density
- AC/DC conversion

Flow Battery Architecture Options

Lower voltage battery pack system (12 or 48V)

Pros:
- Very safe low voltage DC system
- high battery capacity utilization due to smaller mismatch
- Simplify the BMS requirement and the cost

Cons:
- More challenging power electronics due to low voltage high current on the battery side

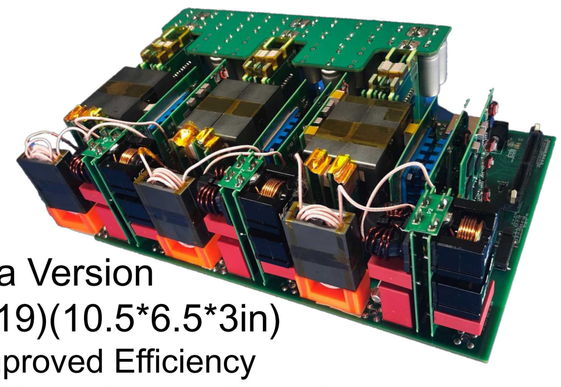
High voltage battery pack system (400V)

Pros:
- Simplify power electronics requirement

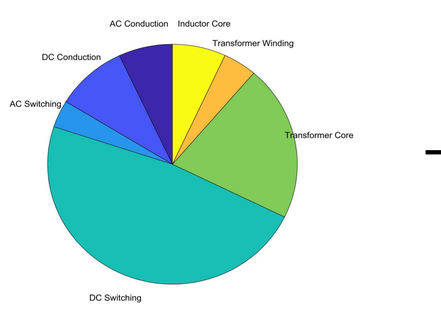
Cons:
- High voltage DC system safety hazard
- Lower utilization of battery capacity due to larger mismatch
- Complex BMS requirement

Accomplishments

Alpha Version(2018):
- Prove of Concept
- Single-Phase System Operation
- Thermal Performance Verified

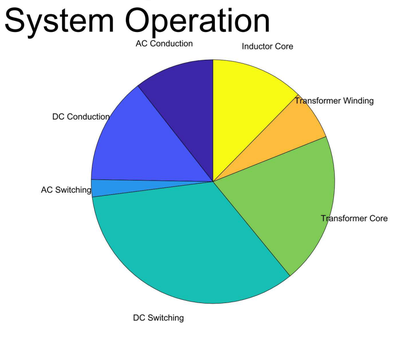


Beta Version (2019)(10.5*6.5*3in)
- Improved Efficiency
- 3-Phase System Operation

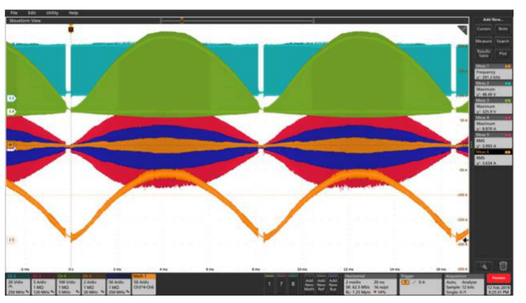


Loss Breakdown (4.4% of Total Power) (Peak Efficiency at 3.6kW)
- DC low voltage switching loss takes majority
- Transformer core limit switching frequency

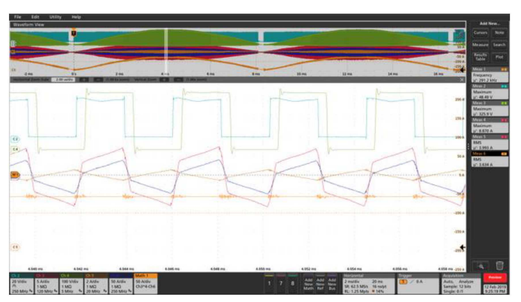
Improvement:
- Transformer core re-design
- Lower switching frequency



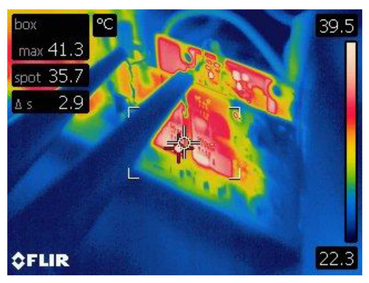
Proposed Loss Breakdown (2.5% of Total Power) (Peak Efficiency at 7.6kW)
- Lower switching frequency enable lower switching loss
- DC low voltage loss reduction enable lower overall loss
- Lower loss will improve thermal performance



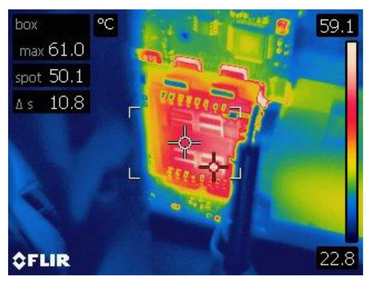
(a) Operating Waveform at 1kW Load



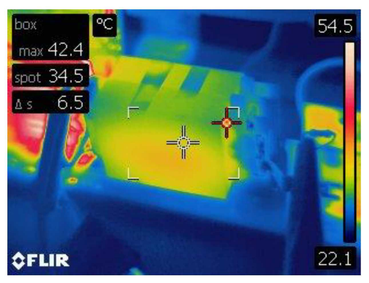
(b) Detailed Operating Waveform at 1kW Load



650V GaN Card (41.3 °C)



80V GaN Card (61.0 °C)



Transformer (42.4 °C)

System Thermal Performance without heatsink, with forced air, at 1kW

Advantages and Potential Impacts

- Efficient and high power density utilizing soft switching GaN power electronics
- Modular, scalable and plug-and-play solution for 10 to 100 kW storage system
  - In-rush current free enables plug-and-play
  - Fault tolerant parallel architecture improves reliability and allows easy scaling of the storage capacity
  - Mix different battery chemistries is also possible

References

- Q. Tian et al., "A novel energy balanced variable frequency control for input-series-output-parallel modular EV fast charging stations," 2016 IEEE Energy Conversion Congress and Exposition (ECCE), Milwaukee, WI, 2016, pp. 1-6.
- 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), San Antonio, TX, 2018, pp. 723-728.

Acknowledgement

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