# A Novel Single Stage Bidirectional AC-DC Converter with Simplified Modulation Strategy for Intelligent Home Battery Energy Storage System

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## Previous Work & Motivation

Due to the increasing penetration levels of power generation and transmission from distributed grid system, Battery Energy Storage System(BESS) serves as critical role for future residential grid backup.

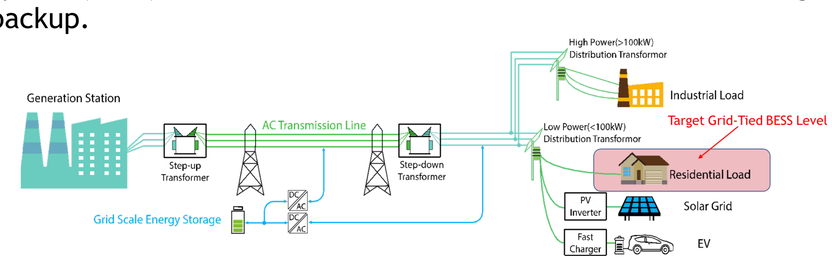
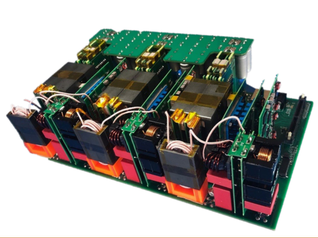
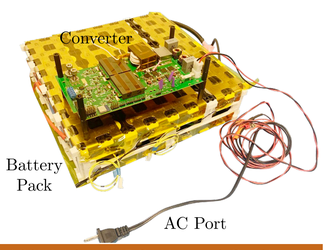



Fig 1. Grid-tied BESS Diagram Example

Previous work on single stage AC-DC converters in SPEC have ranged from 10kW for 3Φ grid to 800W 1Φ grid, with battery voltage ranged from 12.8Vdc to 48Vdc. More then 10 conference & journal papers are published.



10kW 3Φ-AC/DC, Forced Air Cooling
97% Peak Efficiency
50W/in$^3$




600W 1Φ-AC/DC, Natural Cooling
95.8% Peak Efficiency
30W/in$^3$

Fig 2. Previous SPEC BESS Project Work

SPEC proposes a novel single stage series-resonance converter topology with simple fixed-frequency single phase shift modulation for 240Vac/96Vdc application begins from FY23. A hardware prototype with LFP battery is designing and pending demonstration.

## Converter Topology Analysis

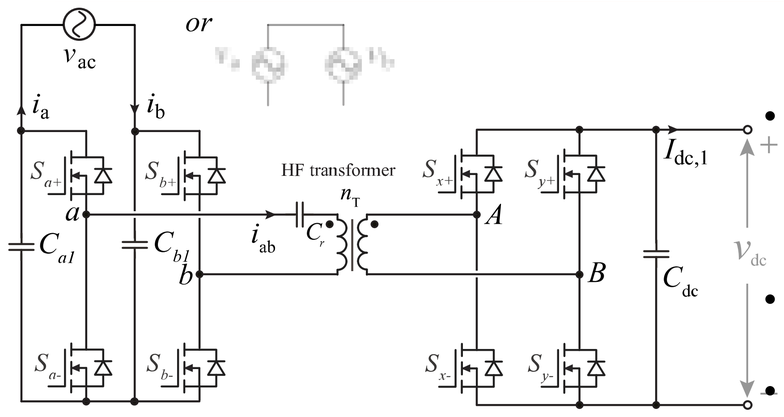



Fig 3. Proposed Novel Single Stage Converter Topology

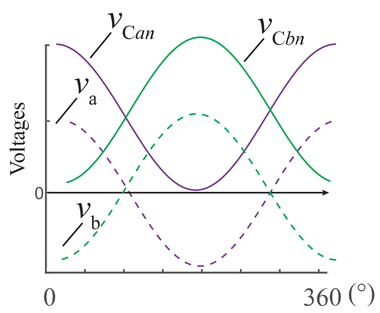



Fig 4. Natural AC Voltage Clamping by Half Bridge Diodes & Caps

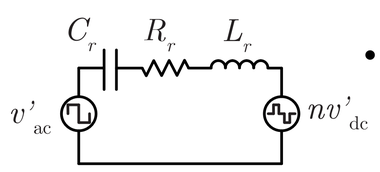



Fig 5. Simplified Two-Port Network

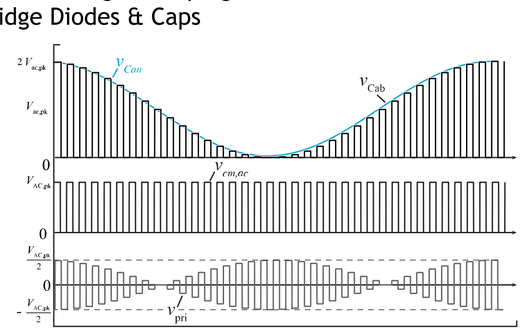



Fig 6. Voltage Waveform on Primary Side

- Primary Side has novel bridge structure, the input AC voltage is naturally clamped by body diodes and decoupling caps.
- Unidirectional Switches enable bipolar primary side square waves.
- Series resonance active bridge mode is employed to further reduce the RMS current flowed into high frequency transformer.
- Two half bridges on primary side are switching synchronously, while only single-phase-shift(SPS) between primary and secondary side bridge with fixed-frequency modulation is employed.
- Small AC cap enables plug-and-play manner.
- PFC & Full AC Range ZVS guaranteed.
- Complex AC-DC Control achieved.

## Operation & Simulation

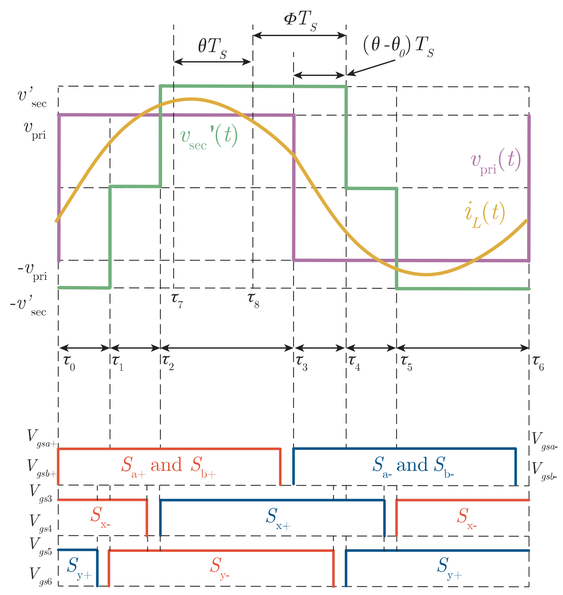



Fig 7. Typical AC-DC Mode PWM Switching Pattern with Voltage & Current Waveform applied across Transformer

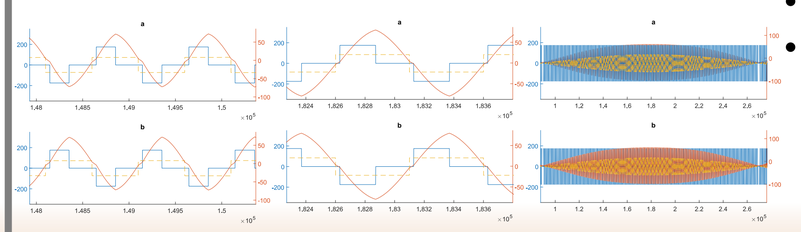


Fig 8. Simulated Voltage & Current Waveform Applied Across Transformer at Vac = 30°, 90° and Half AC Line Cycle

- PFC function is achieved by controlling the instantaneous power flowing through transformer:

$$P_{PFC}(t) = V_{grid} I_{grid} \sin^2(\omega t) = \int_{\tau_0}^{\tau_6} v'_{ac} i_{Lr}(\tau, t) \mathrm{d}\tau$$

- Zero-Voltage-Switching(ZVS) soft switching is achieved by setting the turn-ON current to be negative for each transistor:

$$|i_{Lr}(\tau_0, t)| \geq \frac{v_{ac}(t)}{\sqrt{L_r / 2C_{oss,ac}}}$$

$$|i_{Lr}(\tau_1, t)| \geq \frac{v_{dc}(t)}{\sqrt{L_r / 2C_{oss,dc}}}$$

### Topology Advantages

- Much simpler AC-DC Modulation.
- More comprehensive circuit analysis.
- Higher estimated AC-DC efficiency & power density.

10kW 1Φ-AC/DC, Forced Air Cooling
97.8% Peak Efficiency
70W/in$^3$

Fig 9. Design Target on Novel Topology Converter

H. Zou, el, "Real-time ZVS Range Improvement Control under Light Load for Single Stage Series-Resonant AC-DC Converter," 2024 IEEE Applied Power Electronics Conference and Exposition (APEC), Long Beach, CA, USA, 2024.

## Future Work

Beginning from FY23, the project will focus on hardware design and experimental demonstration with single phase grid and 96V battery pack bidirectional voltage source. The design target of the converter system is 10kW average power with >97.8% AC-DC maximum efficiency and >70W/in$^3$ power density.

The novel single stage bidirectional AC-DC converter will be designed to integrate with residential LFP battery packs. The combined prototype enables energy system integration solution, which provides superior competitivity compared with state-of-art commercial products.

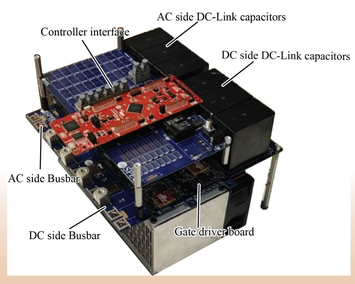



Fig 10. Proposed Hardware Prototype without Transformer.

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