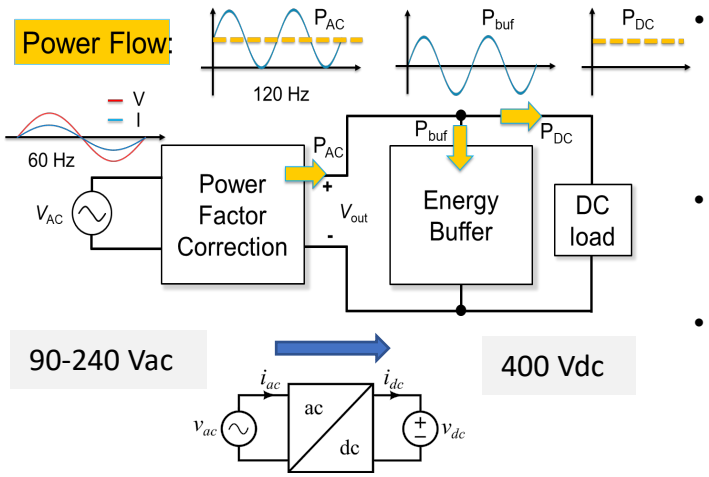
High Performance Single-phase Ac-dc Conversion with Advanced Topology and Control

Berkeley Power and Energy Center

Motivation and Application



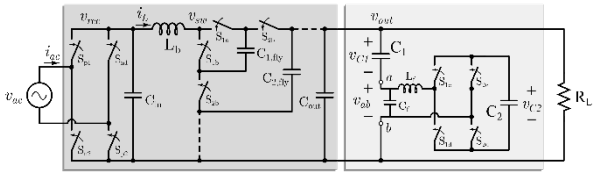
- 90-240 Vac to 400 Vdc is a critical conversion stage for applications such as data center power delivery, electric vehicle charging, etc.
- Ac-dc power factor correction

  Reduce boost inductor size
- Twice-line frequency power ripple buffering

  Reduce buffer capacitor size

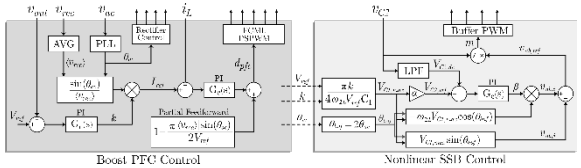
Challenges and Solutions

Topology



- The boost inductor size is reduced flying capacitor multilevel (FCML) topology
- An active buffer topology - series-stacked buffer (SSB) is implemented to reduce the buffer capacitor for twice-line frequency power ripple buffering

Control

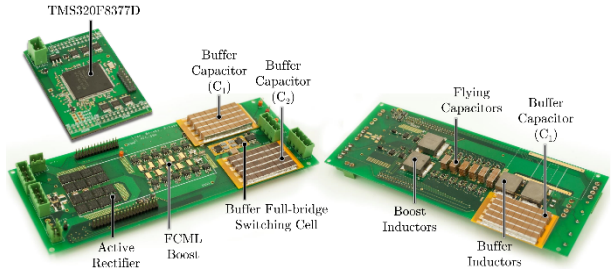


PFC+SSB Coupled Control:

- **PFC Multi-loop control**: high-bandwidth "inner" current & low-bandwidth "outer" voltage loop
- **PFC Partial feedforward** cancels the input voltage disturbances to input current caused by smaller boost inductor in FCML
- **Buffer control** obtains phase and amplitude information from PFC

Hardware Implementation

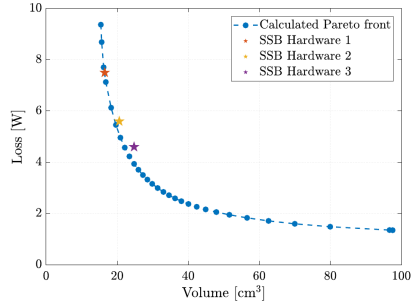
90-240 Vac to 400 Vdc, 1.5 kW PFC converter [1]



- Single DSP TMS320F28377D for the proposed system control
- GaN System and EPC GaN FETs used in FCML and SSB for high efficiency

Multi-objective optimization for SSB [2]

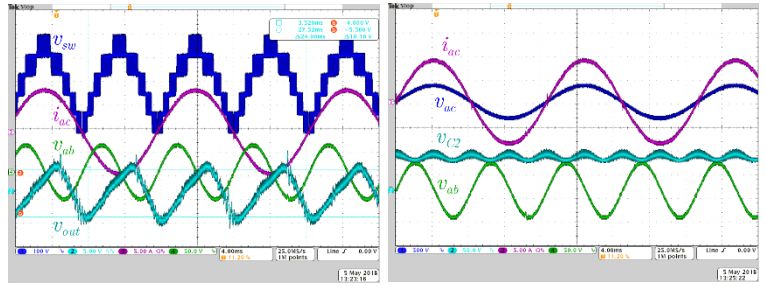
Loss-volume Pareto front of SSB generated with numerical optimization method



$$\min_{C_1, C_2, V_{C2,dc}} \quad \alpha \cdot \frac{f_{loss}}{F_{loss,\,max}} + (1-\alpha) \cdot \frac{f_{volume}}{F_{volume,\,max}}$$
$$s.t. \quad g_i \le 0 \quad \forall i = 1, .., 4.$$

Experimental Verification

Total box-volume power density:	**230 W/in³**
Peak efficiency:	98.9%
1.5 kW efficiency:	98.1%
THD:	< 5%
Power factor:	> 0.994



Experimental waveforms demonstrating power factor correction, multi-level switching, and SSB @ 1.5 kW, 240 Vac to 400 Vdc

References:

[1] Z. Liao. N. C. Brooks, and R. C. N. Pilawa-Podgurski, "A high power density power factor correction converter with a multilevel boost front-end and a series-stacked energy decoupling buffer," in 2018 IEEE Energy Conversion Congress and Exposition (ECCE), 2018

[2] Z. Liao, et al. "Multi-objective optimization of series-stacked energy decoupling buffers in single-phase converters," in 2018 IEEE19th Workshop on Control and Modeling for Power Electronics (COMPEL), July 2018, pp. 1–7.

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