Resilient "Plug-n-Play" Storage Integrated Electricity Solutions for Off-Grid Communities

Acknowledgment — DOE OE Energy Storage Program

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NEED FOR ENERGY RESILIENCY

- While most of us take the power grid for granted, some communities are off-grid
- This includes thousands of people, many living in Native American nations, or in remote areas
- High-impact low-frequency events (e.g., hurricanes, flooding, wildfires, cascading outages, or cyber-physical events) can cause extended outages on the grid
- There is a need for a resilient, cost-effective, flexible solution

Challenge:

Existing state-of-the art solutions use power converters to supply single homes and are large, bulky and very expensive, poses safety hazard, is limited in expansion capability, often home rewiring – requires skilled technician to install

AC-CUBE — A RESILIENT PLUG-N-PLAY BUILDING BLOCK

VISION: Safe, flexible, reliable, modular, and resilient plug-n-play building block, that can be used individually or scaled as needed, to address a range of applications and fulfill the electric power needs of off-grid homes and communities

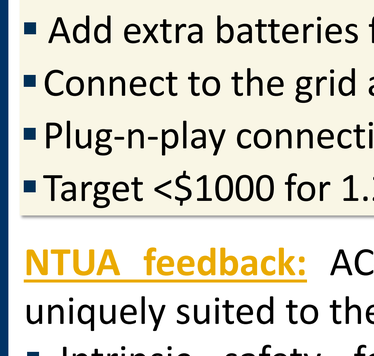
- >1 kW "AC-Cube" with built-in 1 kWh, 48 VDC battery
- DC/DC conversion stage for additional distributed energy resources
- Stack AC Cubes for higher power
- Add extra batteries for longer run times
- Connect to the grid at the main AC panel to supply sub-circuits
- Plug-n-play connection to form ad-hoc microgrids
- Target <$1000 for 1.25 kW/1 kWhr AC Cube w/ internal battery

NTUA feedback: AC-Cube delivers low-cost AC power while being uniquely suited to the following requirements of the Navajo Nation:

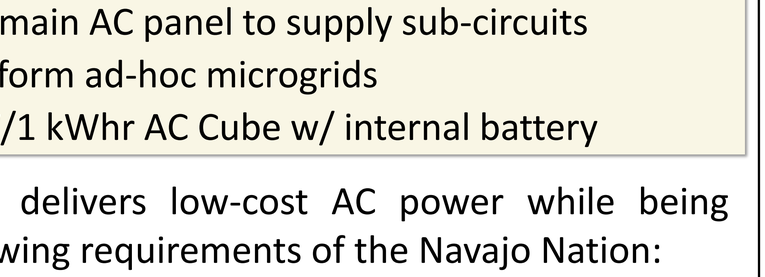
- Intrinsic safety for rapid installation by electrically untrained members
- No exposed high-voltage terminals
- Highly portable and mobile, enabling community members to travel to engage with family and participate in community ceremonies
- Stacking of modules enables incremental investments
- System intelligence enables a wide variety of user installation options
- Integrated power monitoring enables "distributed utility" service-based models

INERTIA-LESS ISOLATED CONVERTER (IIC)

IIC Control



IIC Topology

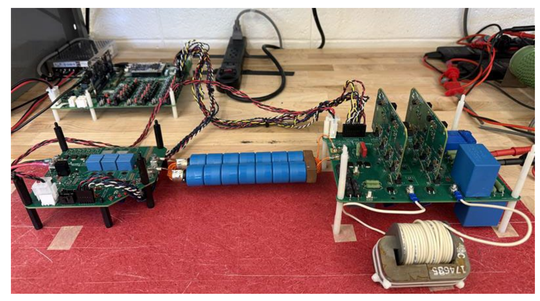


Main topology attributes:

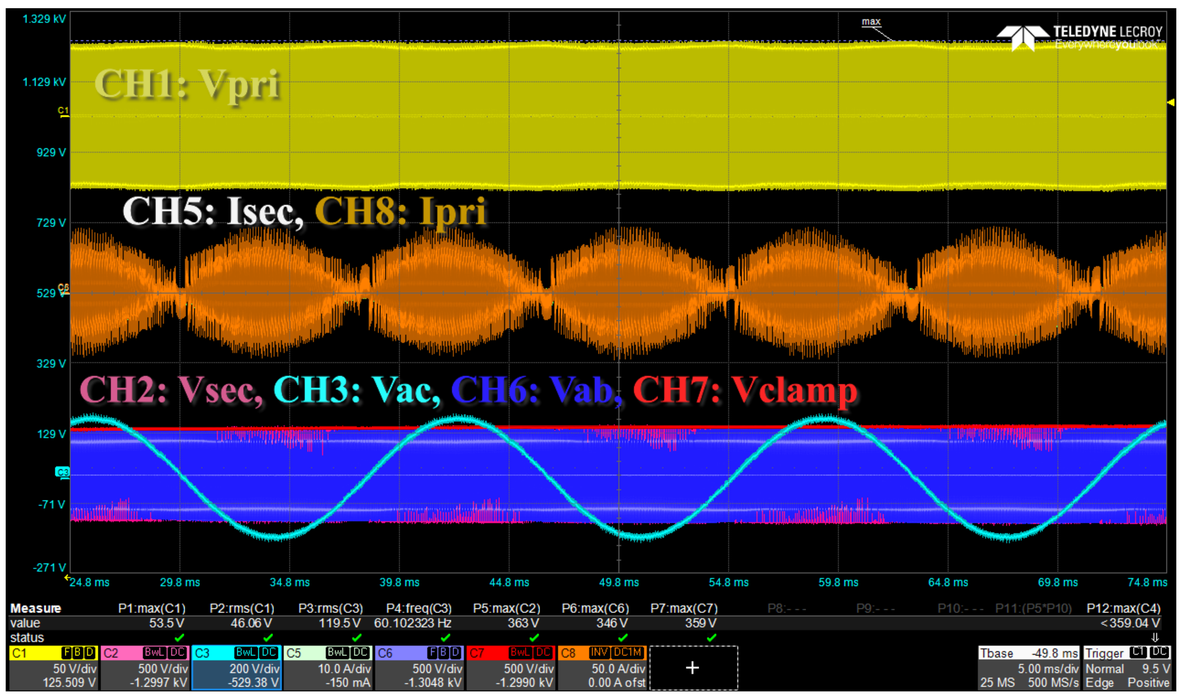
- Single-stage isolated DC/AC conversion with inertia-less (no intermediate storage element) configuration, ZVS for AC bridge
- Local storage at the main DC-bus w/ resource additions through DC-DC power converters
- Ultra-low leakage inductance, high-power density coaxial transformer
- SiC MOSFET bidirectional switches for AC operation
- Grid-interactive operation, i.e., grid-connected and off-grid

IIC HARDWARE PROTOTYPE AND RESULTS

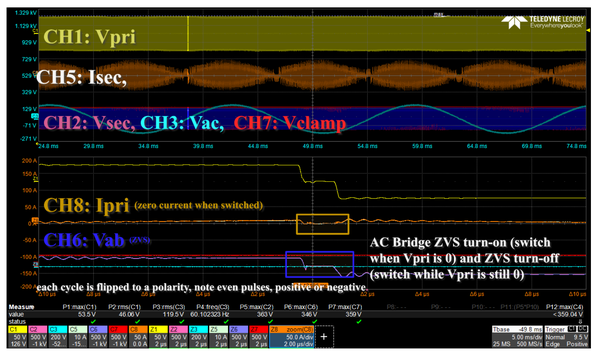
Parameter	Value	Parameter	Value
AC voltage and freq.	120V, 60Hz	Rated power	1kW
DC voltage	48V	Turns ratio	1:5
f_{sw}	40kHz	(Experimental)	(1:17)
Filter inductance (L_f)	8mH	$L_{lk\ (LV\text{-}side)}$	86.5nH
Filter capacitance (C_f)	4µF	$L_{m\ (LV\text{-}side)}$	450µH
DC-side switches	IPP018N10N500 (100V Si MOSFET)		
AC-side switches	G3F25MT06K (650V SiC MOSFET)		



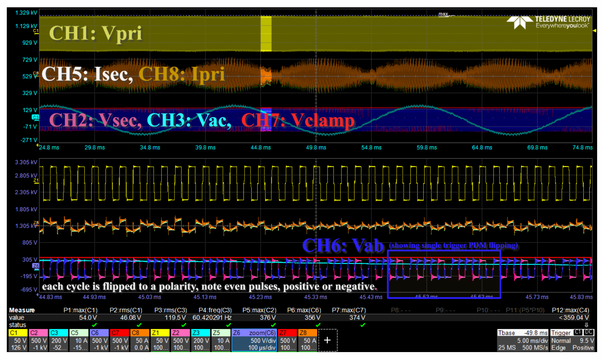
Experimental prototype showing the AC and DC bridge converters, and the designed CWT



Experimental results demonstrating the AC-Cube operation and showing the voltage and current of the high-frequency transformer, and the output AC voltage



Switching-level waveforms demonstrating ZVS



Sigma-Delta modulation hardware validation

AC-Cube Battery Pack

Battery Pack Specifications:

- LiFePO4 32700, 3.2-V, 6-Ah (better protection against thermal runaway and longer life, >2000 cycles)
- **Nominal Pack Voltage:** 44.8-V
- **Building block:** 14S2P, 537.60-Wh
- **Battery pack capacity:** 2 x 14S2P = 1.075-kWh
- **Peak Discharge:** 6A @ 1C

AC-Cube Battery Pack

- **Enclosure Dimensions:** 7.00 in (W) × 9.00 in (D) × 5.25 in (H)
- **Material:** ABS casing material w/ melamine insulation
- **Cooling:** Peltier HP-199-1.4-1.5. Total ΔT within cell cluster = 18.6C

SUMMARY & PUBLICATIONS

Successfully designed, developed, and experimentally tested the first AC-Cube prototype (including battery pack)

Publications

- S. Belkhode, N. Prabhu, J. Benzaquen, and D. Divan, "Single-Stage Bidirectional Inertia-less Isolated DC/AC Converter," *2024 IEEE Applied Power Electronics Conference and Exposition (APEC)*, Long Beach, CA, USA, 2024, pp. 348-353, DOI: 10.1109/APEC48139.2024.10509397.

Presentations:

- S. Belkhode, J. Benzaquen, D. Divan, "Single-Stage Inertia-Less Isolated Bidirectional DC/AC Converter", *2024 IEEE Applied Power Electronics Conference and Exposition (APEC),* Long Beach, CA, USA, 2024 (Oral Presentation).