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

Georgia Tech Center for Distributed Energy

Acknowledgment — DOE OE Energy Storage Program and Dr. Imre Gyuk

Satish Belkhode, Aniruddh Marellapudi, Joseph Benzaquen, Deepak Divan
Team — Georgia Tech-Center for Distributed Energy, Navajo Tribal Utility Authority, Sandia National Laboratories

NEED FOR ENERGY EQUITY AND RESILIENCY

- While most of us take the power grid for granted, there are communities that are off-grid, or live with poor-quality unreliable power
- This includes thousands of people, many living in Native American nations, or in remote areas where it is difficult to provide and maintain service
- High-impact low-frequency events (e.g., climate change, hurricanes, flooding, wildfires, cascading outages or cyber-physical events) can cause extended outages on the grid, with disproportionate impact on poorer communities
- There is a need for a cost-effective flexible equitable solution for providing power to these communities, such that their quality of life is maintained and possibly enhanced

Challenge: Existing state of the art solutions use PV panels, batteries, and 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

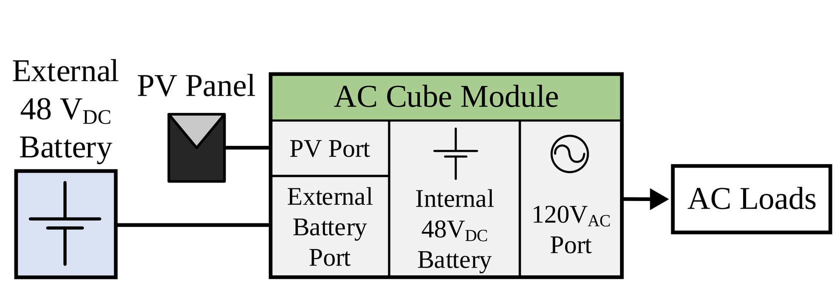
VISION: Safe, flexible, reliable, and resilient plug-n-play building block, that can be used individually or scaled as needed, to address a range of applications and fulfill the electric power needs of off-grid and poor-grid homes and communities

- >1 kW "AC-Cube" >250 W PV panel and 1 kWh, 48 VDC battery
- Stack AC Cubes for higher power, add extra batteries & PV panels for longer run times
- Connect to grid at main AC panel to supply sub-circuits or to return power (needs electrician)
- Plug-n-play connect of multiple AC Cubes to form an adhoc microgrid
- Target <$1000 for 1.25 kW/1 kWHr AC Cube w/ internal battery

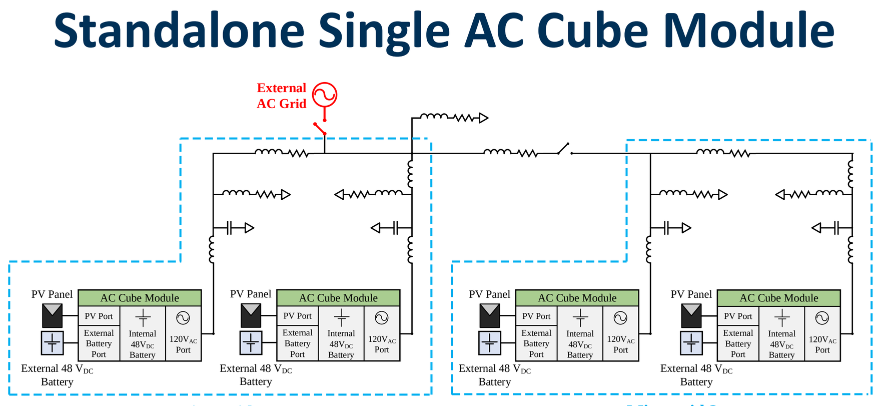
NTUA feedback: AC-Cube delivers low-cost AC power while being uniquely suited to the following requirements of the Navajo Nation:

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

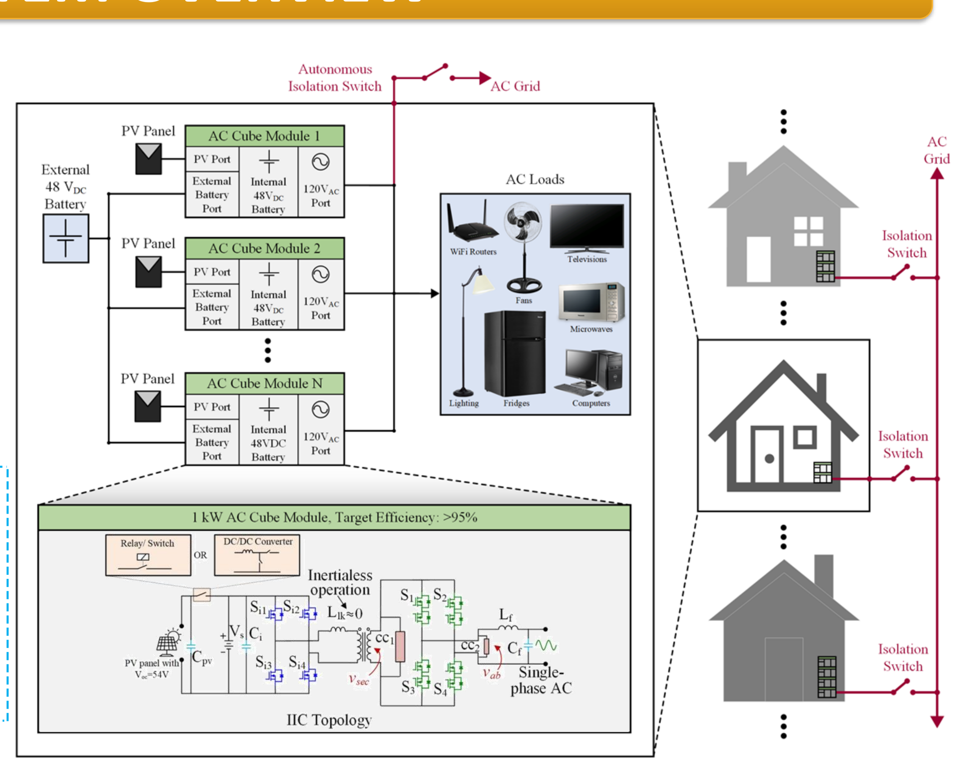
AC-CUBE SYSTEM OVERVIEW



Standalone Single AC Cube Module



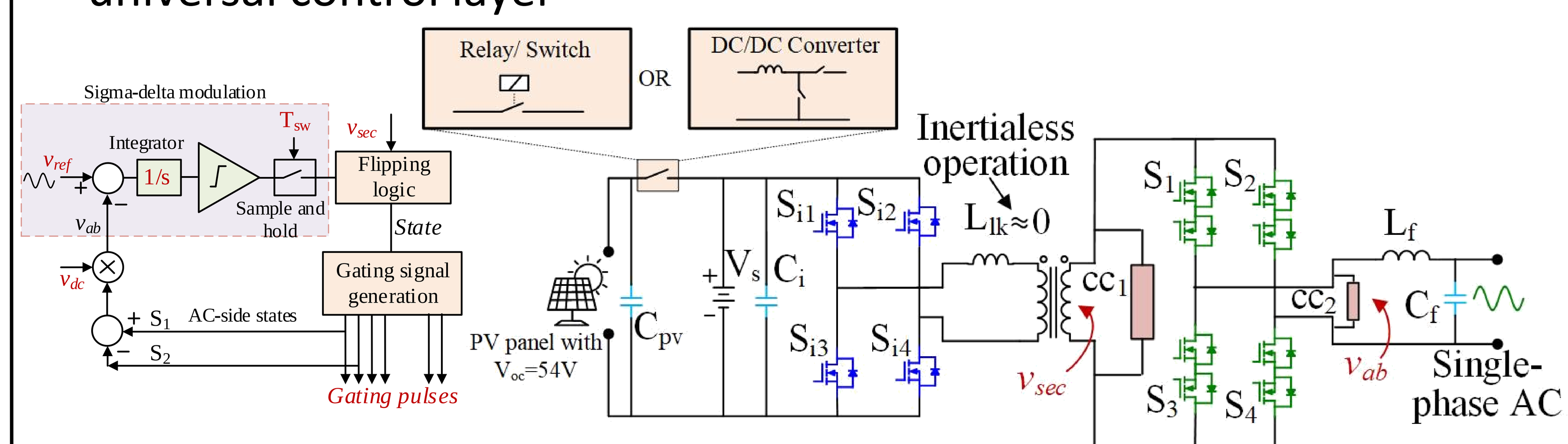
Two Microgrid Systems w/ 2 AC-Cubes



Single/Multi-household Implementation

INERTIA-LESS ISOLATED CONVERTER (IIC)

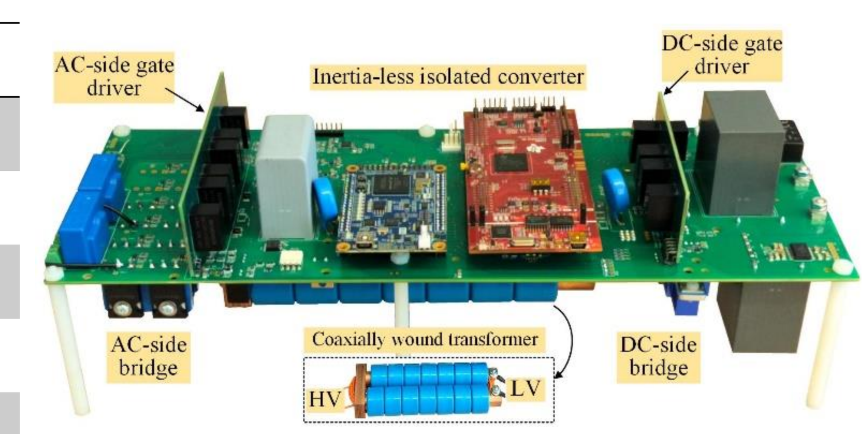
- Inertia-less isolated converters for DC/AC single-phase conversion
- PV added connection to DC-bus
- Low-BOM cost
- Simple and low-cost control implementation using Sigma-Delta control with discrete pulse modulation
- Ultra-low leakage inductance high-power density coaxial transformer
- Grid-interactive operation (grid-forming/grid-following) with outer universal control layer



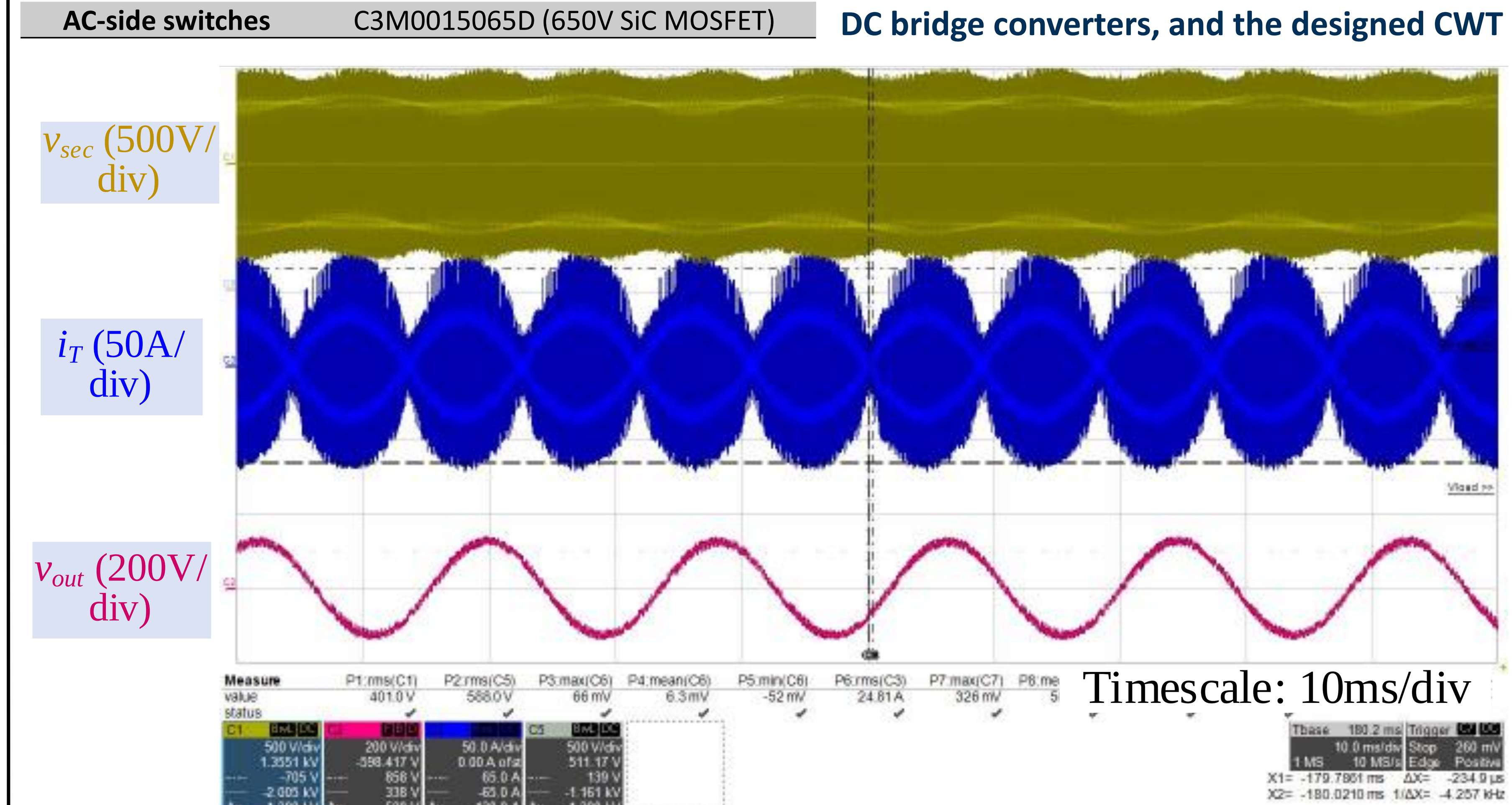
IIC Topology

IIC HARDWARE PROTOTYPE AND EARLY 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	IPB027N10N3G (100V Si MOSFET)		
AC-side switches	C3M0015065D (650V SiC MOSFET)		



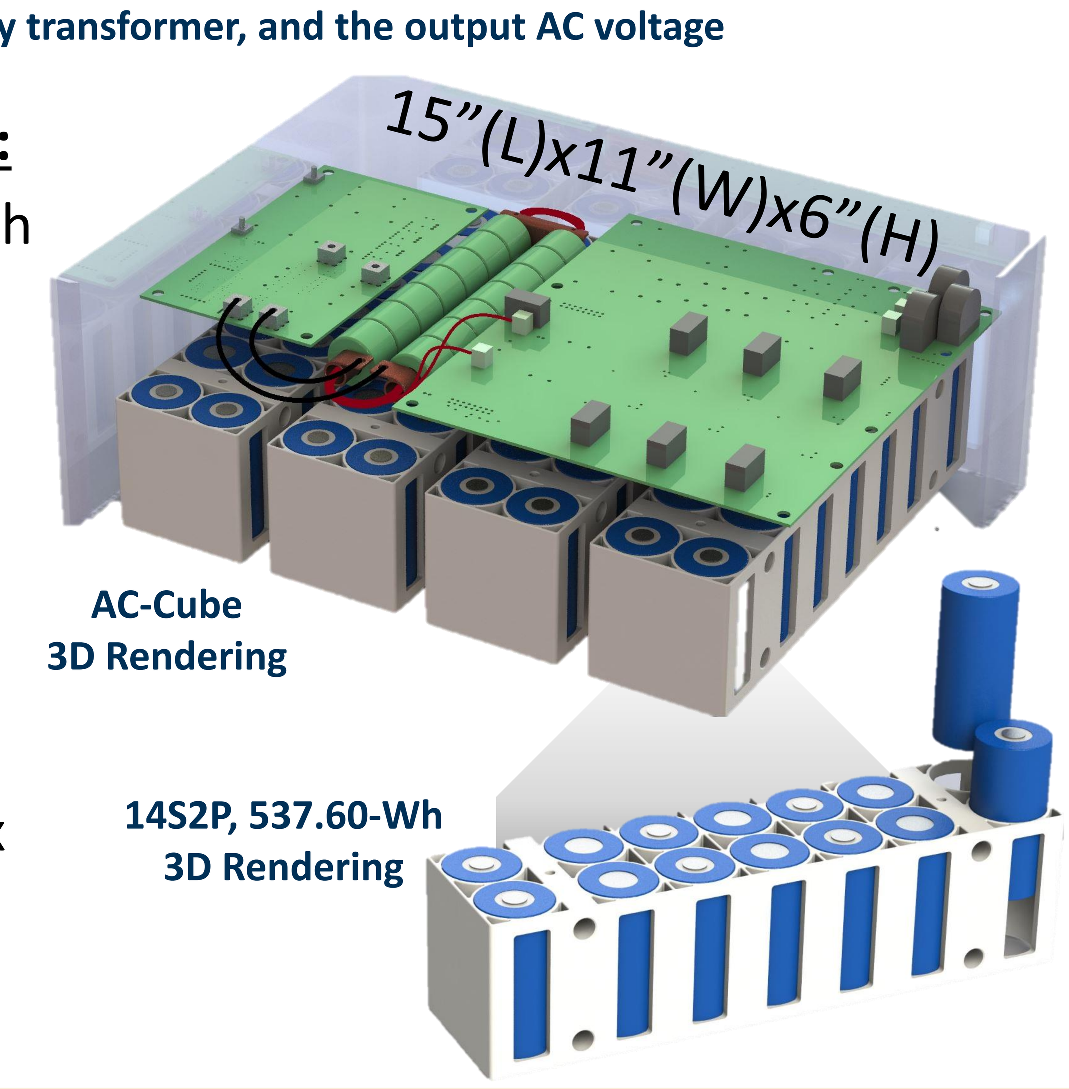
Experimental prototype showing the AC and DC bridge converters, and the designed CWT



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

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



SUMMARY & ACCOMPLISHMENTS

- Successfully designed, developed, and experimentally tested the first AC-Cube prototype
- 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.