Resilient "Plug-n-Play" Storage Integrated Electricity Solutions for Remote Locations

Roundtable on Energy Storage for Social Equity

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06/29/2021

GT Center for Distributed Energy

Georgia Tech Center for Distributed Energy

Creating holistic solutions in electrical energy that can be rapidly adopted and scaled

WORLD ECONOMIC FORUM

TOP 3 TRANSMISSION GRID INNOVATIONS 2010-2020

"Accelerating the Energy Transition"

Platform Initiatives

Grid Asset Augmentation

7.2 kV 50 kVA Hybrid Transformer

13 kV 1 MVA Modular Transformer

Smart Wires

- 13 kV/50 kVA FUT
- 13 kV 1 MW Power Router
- 67 MVA Modular LPT
- Improving Grid Resiliency
- Smart Wires
- Meshed Grid VVC

Energy Access in Emerging Markets

- 'Exponential' Tech
- Self Organizing Nano Grid
- Pay-Go Smart Meter
- Low Cost DA for Grids
- Ad-Hoc Bottom-Up Grids
- Empower a Billion Lives

Emerging Technology: D-Light

Top 10 Emerging Markets
Source: Global Intelligence Alliance

Next Generation Grid Power Electronics

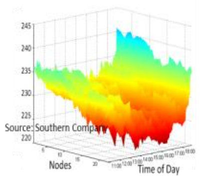
4 kV MVSI for Large PV Farms

7.2 kV 50 kVA SST

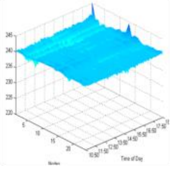
- 5 kV DC Grid Building Block
- 7.2 kV 50 kVA Grid Connected SST
- 4 kV MVSI for Large PV Farms
- Triports for PV/Storage/Grid
- MVSI with Integrated Storage
- Microgrid-Grid Interface Device

Decentralized Grid Control Techniques & Markets

- Grid Edge Volt VAR Control
- Collaborative Control
- High PV Integration
- DER Micro grid Impact
- Self-Pricing Island Grids
- Virtual Power Plants

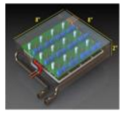


Feeder Voltage w/o and with GE Control



Feeder Voltage w/ Grid Edge Control

Next Generation Industrial Power Electronics



100 kVA EV Drive System

200 kVA Isolated Drives

2 MVA Industrial SIVOM

- Industrial CVR Energy Efficiency
- 100 kVA EV Drive System
- 25-500 kVA Isolated Drives
- Energy Hub – DC Fast Charging
- Programmable Load/Source
- Data Center Power Sources

Global Asset Monitoring Management & Analytics (GAMMA)

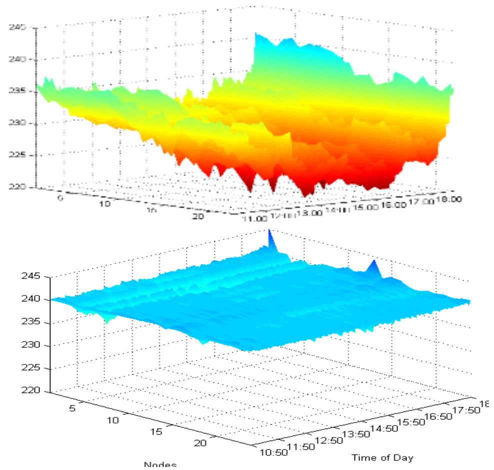
- Low-Cost Communications
- Cyber-Security
- Data Management
- AMI Data Analytics
- Global Sensor Networks
- Cloud Based GAMMA System

GAMMA Platform

Gamma kernel

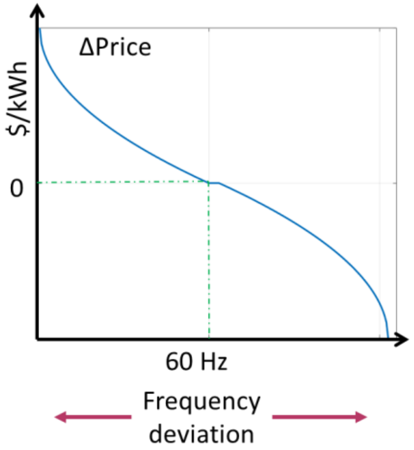
Primary Drivers

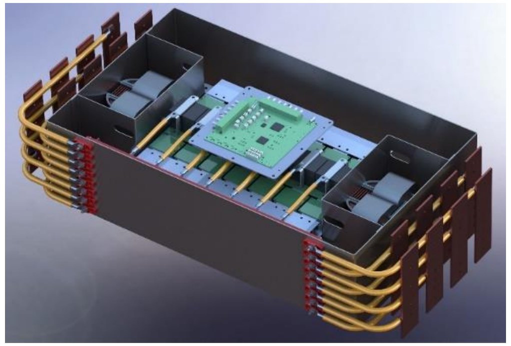
Digitalization Decentralization Decarbonization



COLLABORATIVE CONTROL
Varentec

TRANSMISSION POWER FLOW CONTROL
Smart Wires





SELF-PRICING MICROGRIDS
Transactive/Physical Grid

SOLID STATE TRANSFORMER (S4T)

Need for Energy Equity and Resiliency

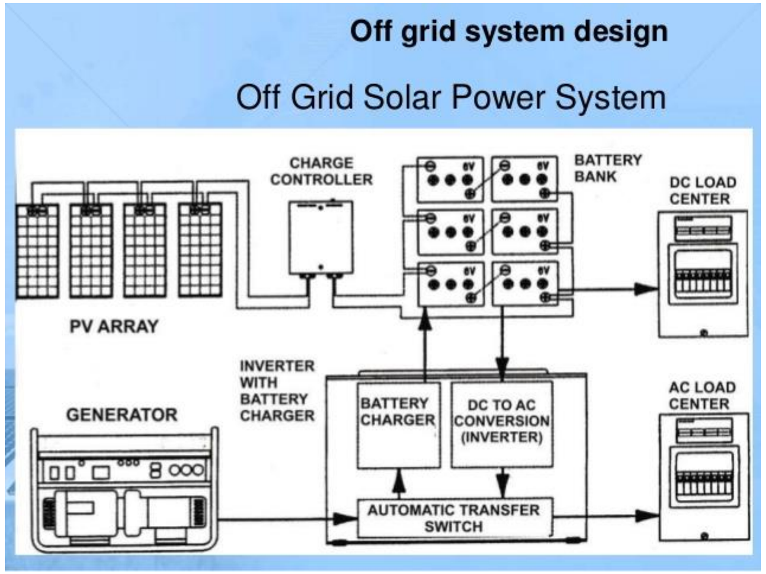
- While most of us in the US take the power grid and its services for granted, there are many communities that do not have access to the grid, or live with poor-quality unreliable power
- This includes thousands of people, many living in Native American nations, or in remote areas where it is difficult to provide and maintain service
- High-impact low-frequency events (e.g., climate change related hurricanes, wildfires and cascading outages caused by equipment failure or cyber-physical events) can cause extended outages on the bulk power system, with disproportionately severe 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

Navajo homes being fitted with PV power

HILF events and grid impact

What are the Available Options?

- Resilience solutions typically include diesel generators and microgrids, which are expensive and require skilled technicians to install and operate the systems – challenging for small communities or single homes
- The other alternative is a solar home system, using PV panels & batteries – typical off-grid home may need 1 kW to >10 kW at 120 volts 60 Hz
- Typical off-grid homeowner would like to:
  - Sustain critical loads, such as lighting, phones, refrigerators and TV/internet connectivity for sustained periods of time
  - Power high-rated loads such as microwaves & appliances as needed
  - Power tools and machines that can provide livelihood
  - Start small and low-cost, expand as needed
  - High flexibility to fulfill daily requirements
  - Avoid high costs related to installation, operation, repair and disposal
- 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



Typical solar home system installation

DOE Sandia Project Objectives

VISION: Safe, flexible, reliable, and efficient 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.

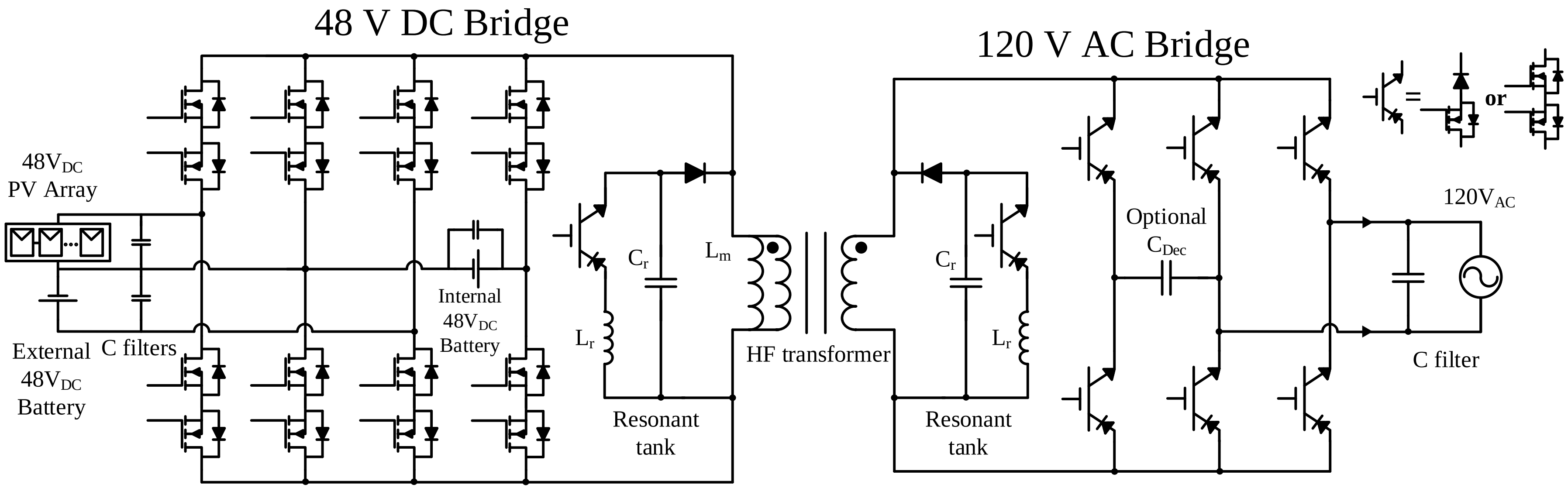
Storyboarding the Requirements:

Worked with the Navajo Tribal Utility Authority (NTUA) and Sandia to better understand the needs, pain-points and use-cases that are typical for an energy constrained community such as the Navajo Nation

- Plug and play allows rapid installation and minimum down-time in resiliency situations
- Touch safe (48 VDC) batteries and PV panels allow homeowners to self-install the system
- Multi-port operation: 120 V AC, solar, batteries, grid, and loads – managing all simultaneously
- Flexible – can support individual loads, or can be stacked to support a house
- Can automatically form a microgrid with other homes if needed
- Automatically supports grid-connected, microgrid, and portable power applications
- Can export power to the grid (if allowed by utility)
- Monitoring and control of the system via cell phones
- Baked in safety and cybersecurity
- No skilled technicians needed to install, operate and maintain – ‘PhD in the Box’

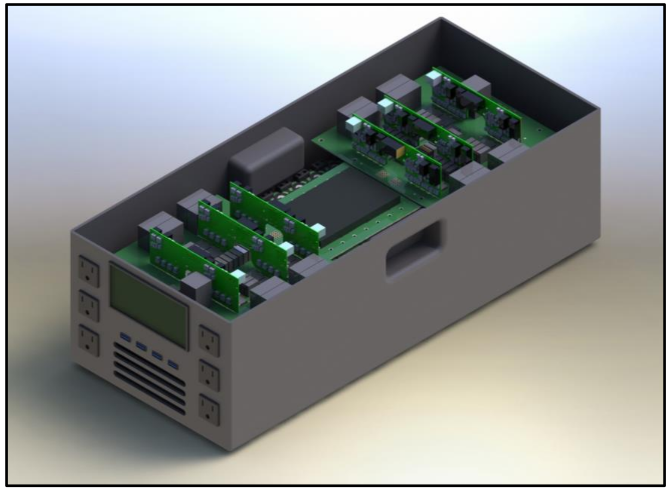
Building Block - AC Cube

- "AC Cube" with 1 kWh internal storage, 120 VAC 1 kW powers most residential loads
- Soft-switching S4T topology for high efficiency, low EMI, and high power-quality
- Integrated and external 48 V DC battery and 24-48 V PV panels ensure intrinsic safety
- Easy install and maximum flexibility to support multiple loads without house rewiring
- Parallel connection of "bricks" allows for higher output power or longer run time
- Configure to return power from PV panels to AC grid or EV under normal conditions
- Advanced diagnostics and system control via smart phone



Target 95% Efficient S4T Multiport Converter

Patents issued and pending



AC Cube Module
Estimated Weight: 5 kg

AC Cube System Overview

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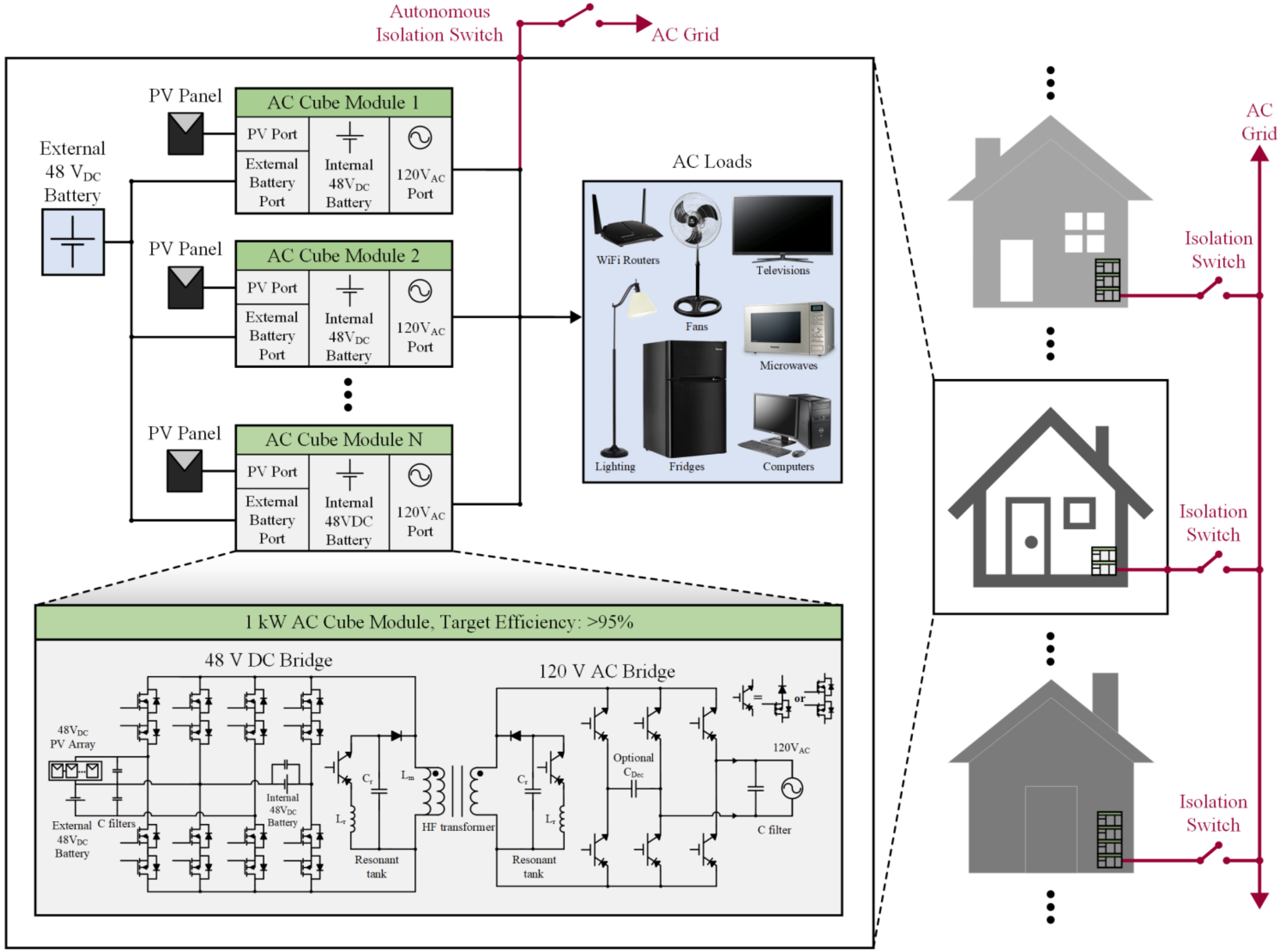

- 1.25 kW "AC Cube" 250 W PV panel and 1 kWh internal and external 48 VDC battery
- Stack AC Cubes for higher power, add extra batteries and PV panels for longer run times.
- Connect stacks of AC Cubes to form a microgrid
- Connect to grid at main AC panel for whole house power and to return power (needs electrician).
- Individual AC Cube modules can be moved to whichever load needs power.
- Target <$1000 for 1.25 kW/1 kWHr AC Cube incl. internal battery, 250 W PV panel, grid connect
- Realize up to $350/year of energy savings per AC Cube (assuming $0.30/kWh in CA).
- Diagnostics and system control via smart phone.

How do you get this level of autonomous flexible control?

Collaborative Control for Grid as an Ecosystem

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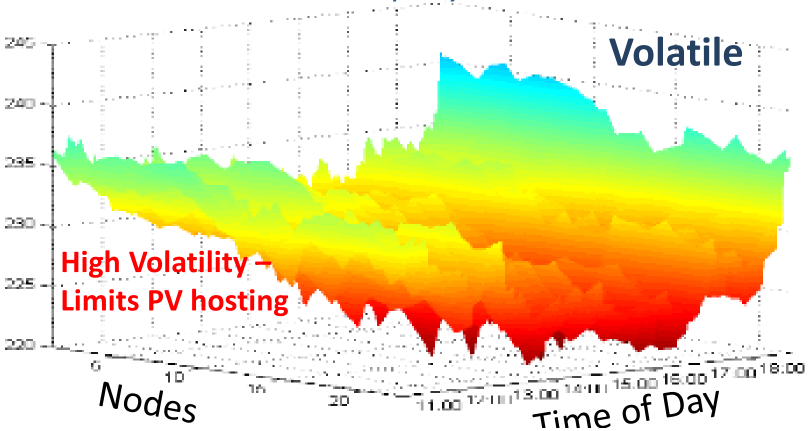
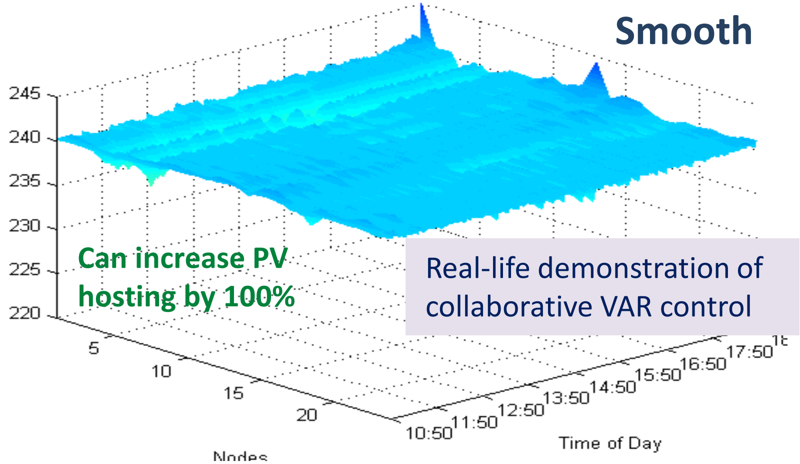
- Centralized control of a future grid with millions of intelligent DERs (storage) will be challenging – complexity, comms latency, security
- ‘Collaborative Control’ allows edge devices (inverters) to use local measurements and standard ‘rules’, acting in real-time to fulfill individual goals, and collaborating to sustain the grid ecosystem
- System is constantly changing, and devices need to act without real-time knowledge of system topology/state or low-latency comms
- Fundamentally different paradigm: today devices view the grid as a resource – with an ecosystem, all need to act to sustain it (priority)

Source: Southern Company and Varentec





Examples of collaboration without communications

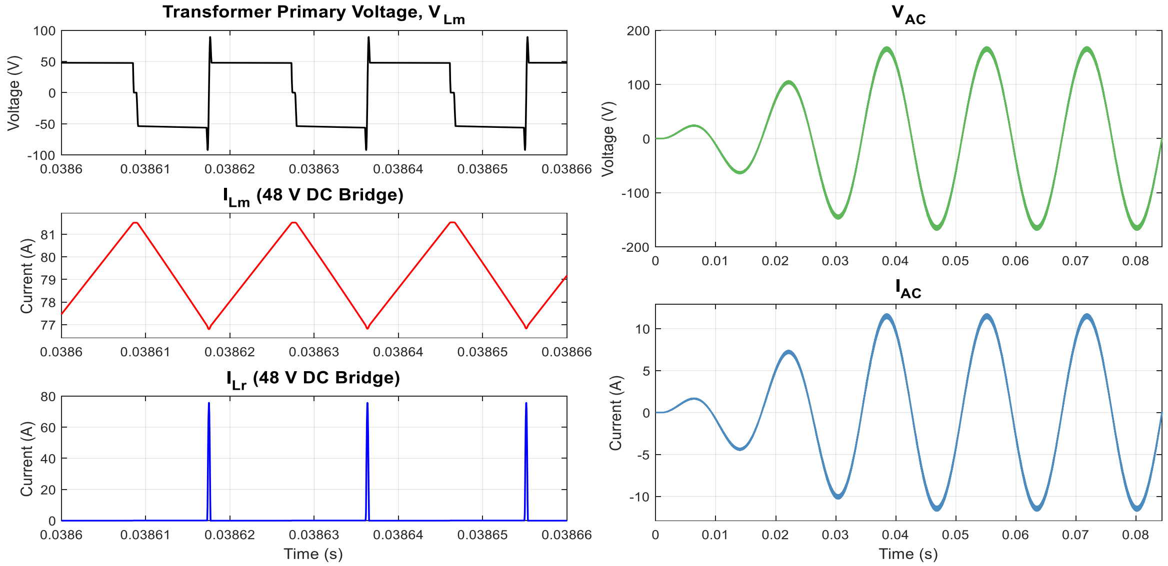
CHANGING WHAT'S POSSIBLE

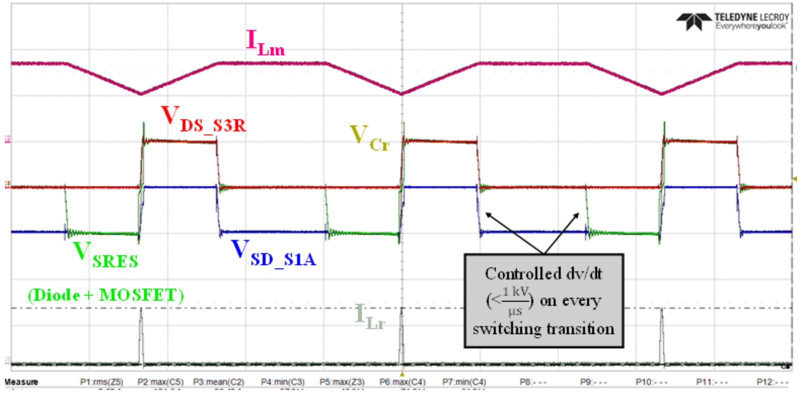
DE-AR0000899

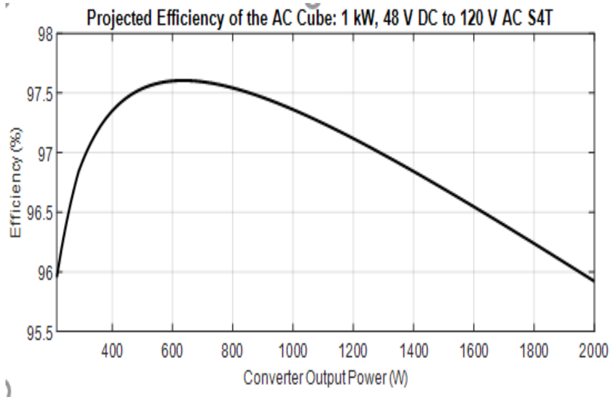
Autonomous inverters that collaborate with minimal system knowledge, don’t interact, operate over wide range of conditions & coordinate with slow secure comms

AC Cube Validation

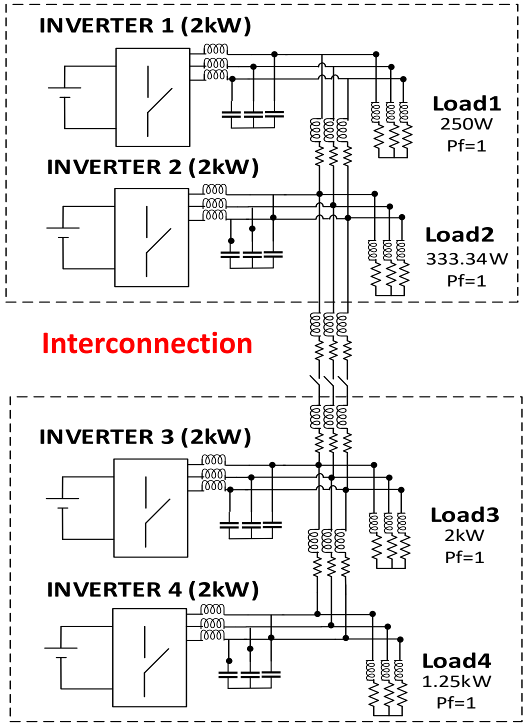
- Validation of AC Cube at 120 V AC (RMS), 1.25 kW (2 kW peak).
- Projected AC Cube efficiency >95% over wide operating range
- Control capability in multiport and microgrid operation validated







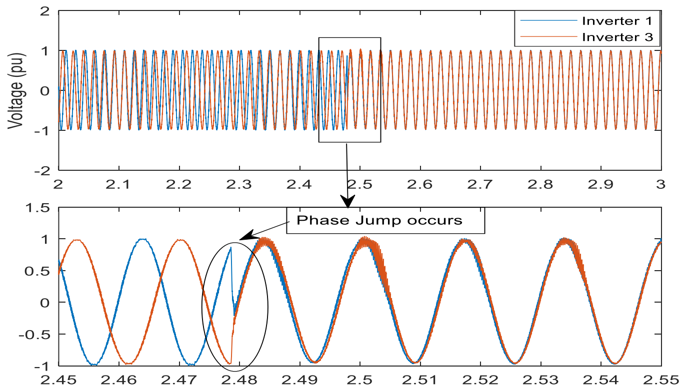
AC Cube single module simulation & experimental results



Autonomous control of self-forming microgrid

Multi-module simulation results for collaborative control

Converter voltages at PCC



AC Module – Design Concept Under Build

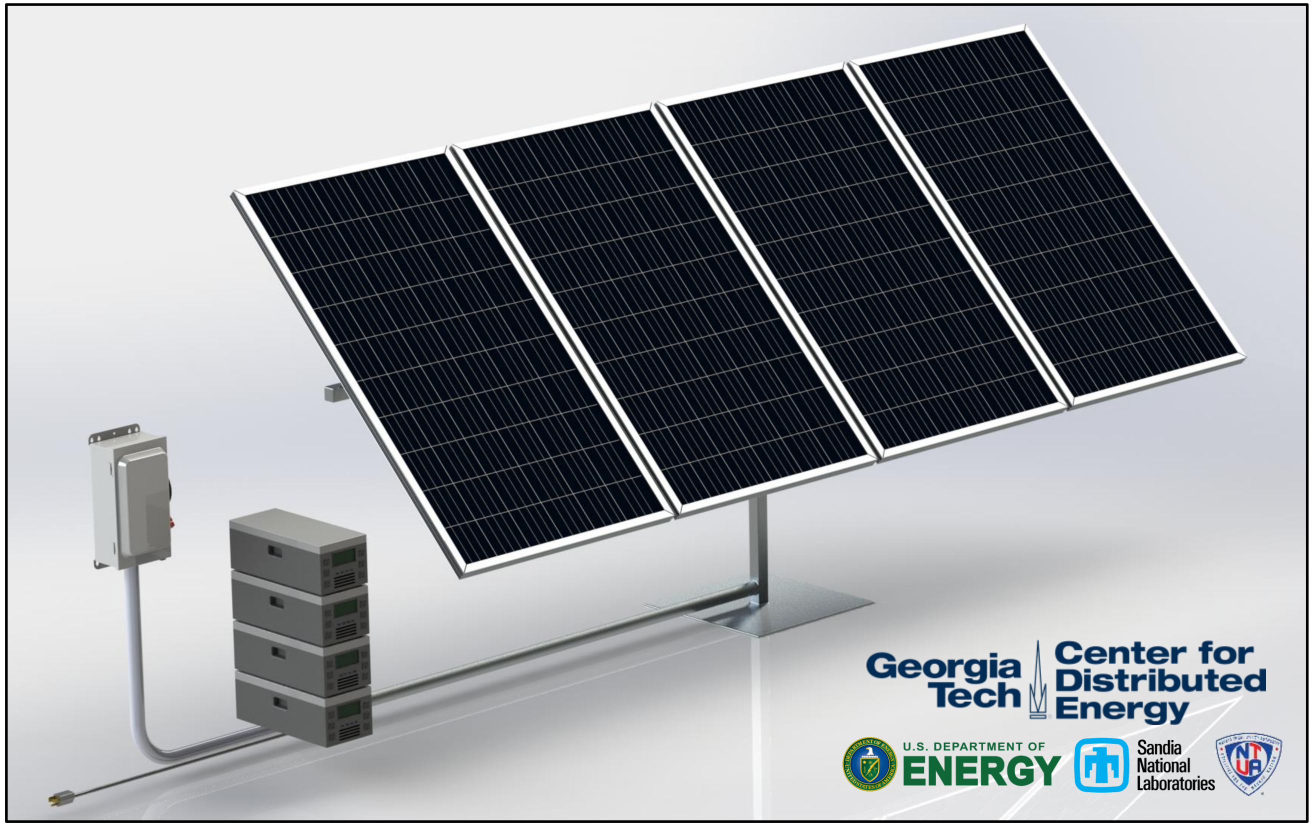
250 W x 4 PV panels → 5 kWHr/day per house (additional possible)

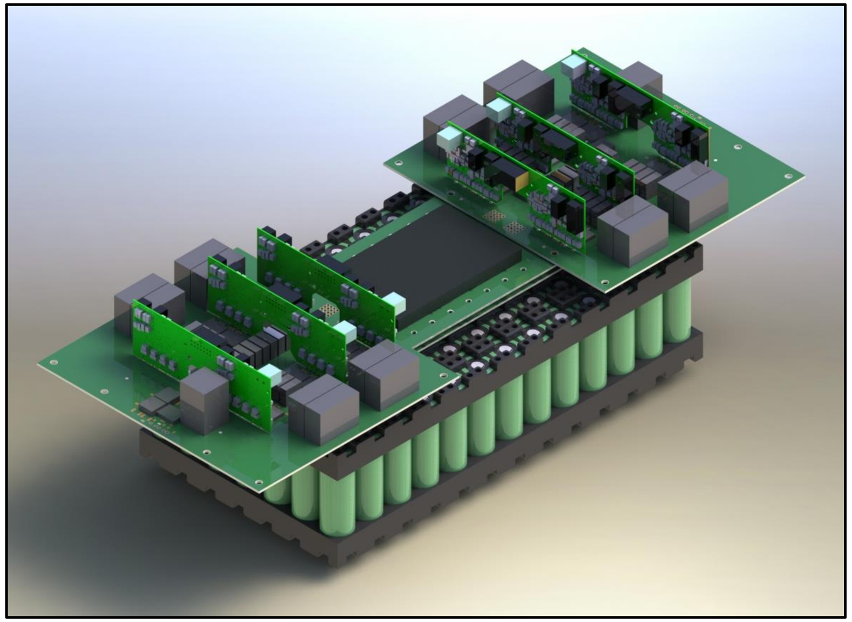
4 x AC Cube per house → 5 kW per stack peak (extend to 10 kW)

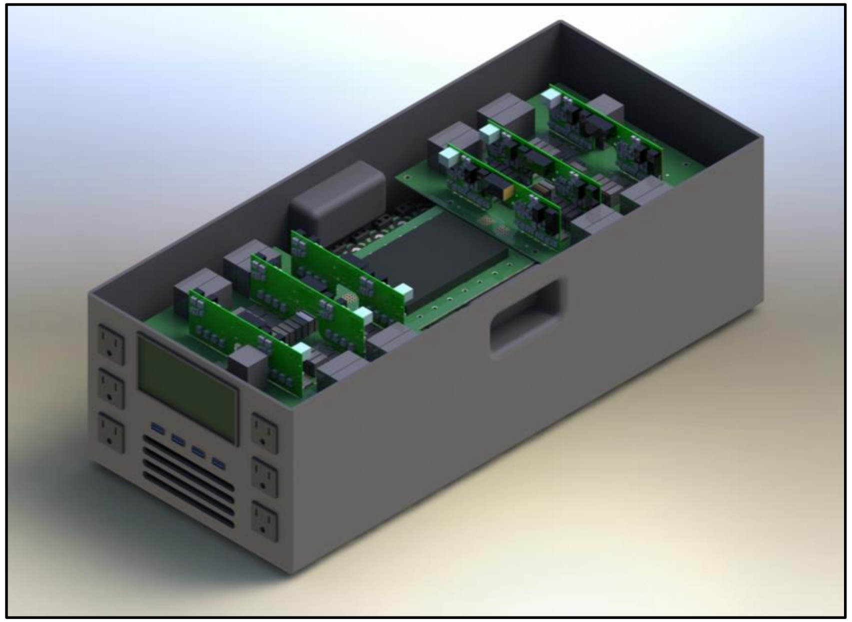
4 kWHr of internal energy storage + external 48 VDC battery (optional)

Use individually (portable) or in a stack - parallel as needed

Self organizing – automatically works grid-connected or islanded







Use Scenarios

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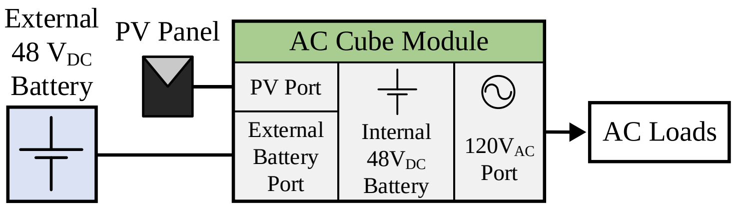
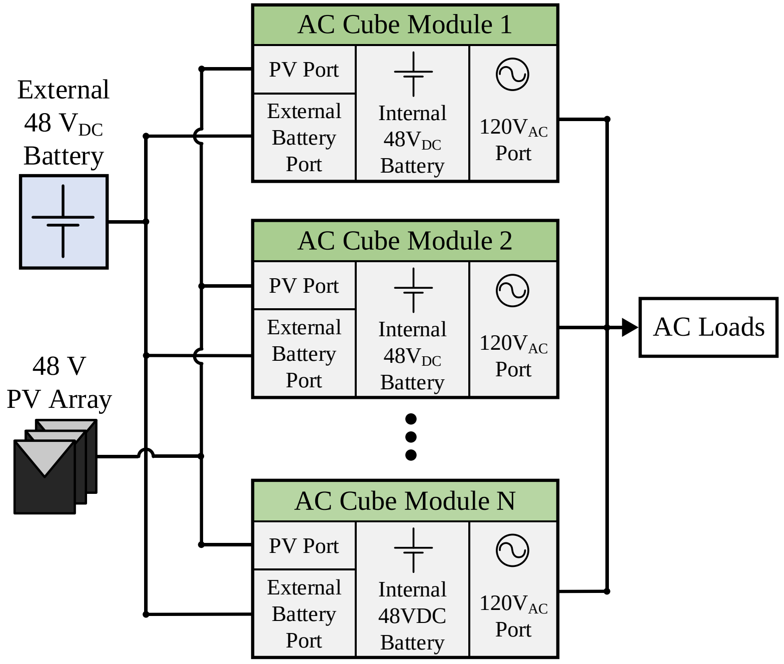
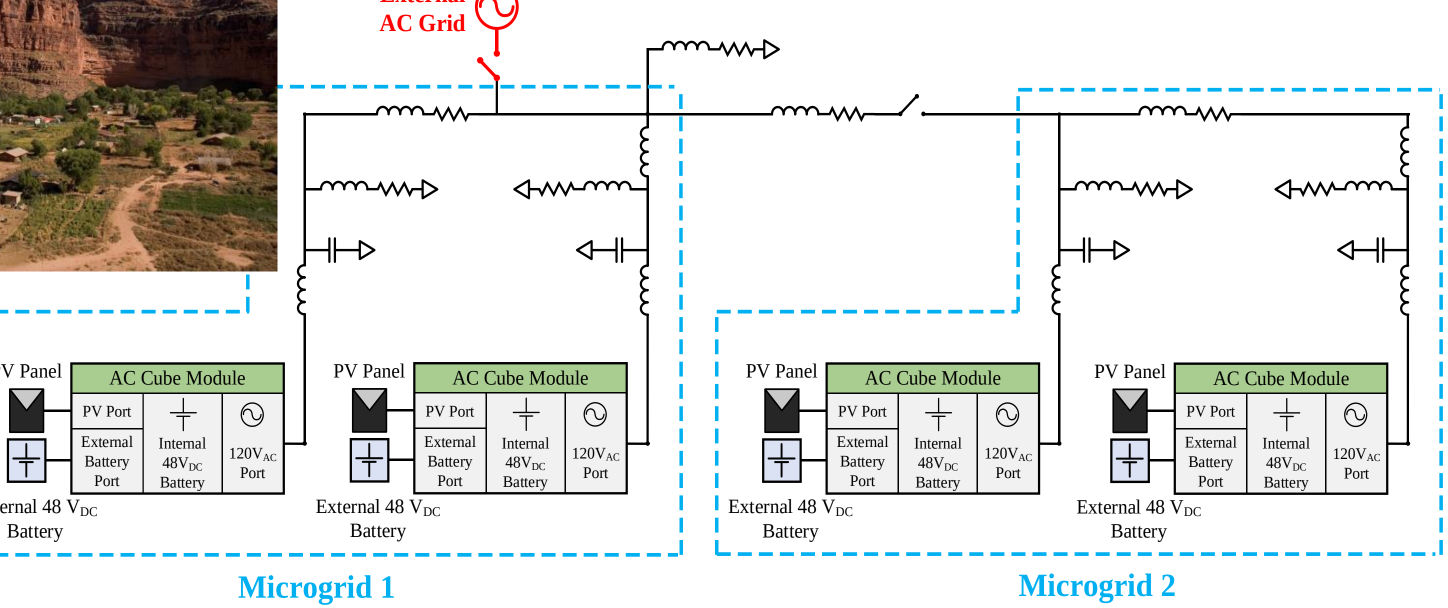


1. Standalone Single AC Cube Module



1. Standalone Stacked AC Cube Modules

3. For emergency deployments in resiliency conditions, ship or airdrop and rapidly deploy using plug-n-play modules.



2. Two Microgrid Systems with Two AC Cubes Each

Alignment with Needs of Navajo Nation

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- Derrick Terry of the Navajo Tribal Utility Authority helped to drive specifications of the AC Cube

- Significant alignment between the needs of the Navajo Nation and the presented capabilities, use cases, install options, and specifications of the AC Cube, a safe, portable, affordable, and reliable AC power source.

- 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
  - Portable plug-and-play AC power for work and community ceremonies
  - Stacking of modules enables output power scalability and incremental investments
  - Low hardware and installation cost
  - Collaborative control enables variety of grid-forming, grid-following & microgrid operating modes
  - High efficiency and high reliability
  - Integrated power monitoring enables “distributed utility” service-based models through NTUA

Monitoring & Controlling Geo-Dispersed Assets

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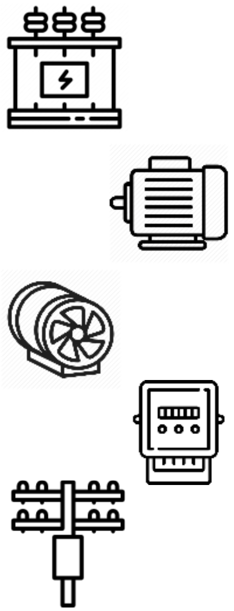
U.S. DEPARTMENT OF ENERGY

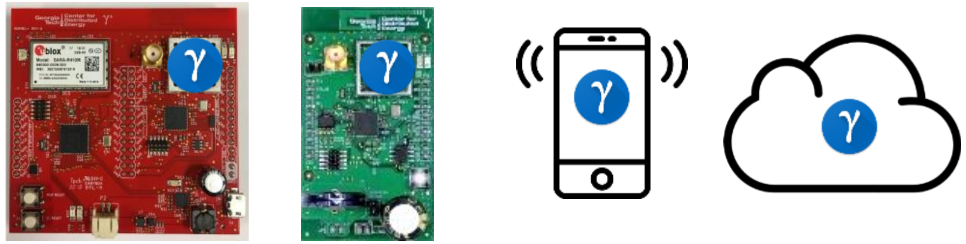
NEED: To manage millions of intelligent edge devices with a low-cost scalable digital platform

GAMMA (Global Asset Monitoring, Management & Analytics) Platform [1] is a uniquely integrated end-to-end framework specifically designed to accelerate the development & deployment of low-cost monitoring & control solutions for fleets of geo-dispersed assets.



Customer assets

GAMMA PLATFORM



Kernel+ | **Kernel** | **Data Mule** | **Cloud**

Specially designed standardized "plug-&-play" architecture

☑ Data analytics, Visualization

☑ Predictive Maintenance

☑ Fast payback, high benefits

Value delivery

End-to-end solution with minimal customization

Examples of GAMMA edge devices

[1] Kulkarni *et al.*, **"Enabling a decentralized smart grid using autonomous edge computing devices"**, *IEEE Internet of Things J.*, Oct. 2019

Energy Access – A Grand Challenge

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Energy Access needs new fresh thinking – holistic solutions, high-impact, scalable and lower cost

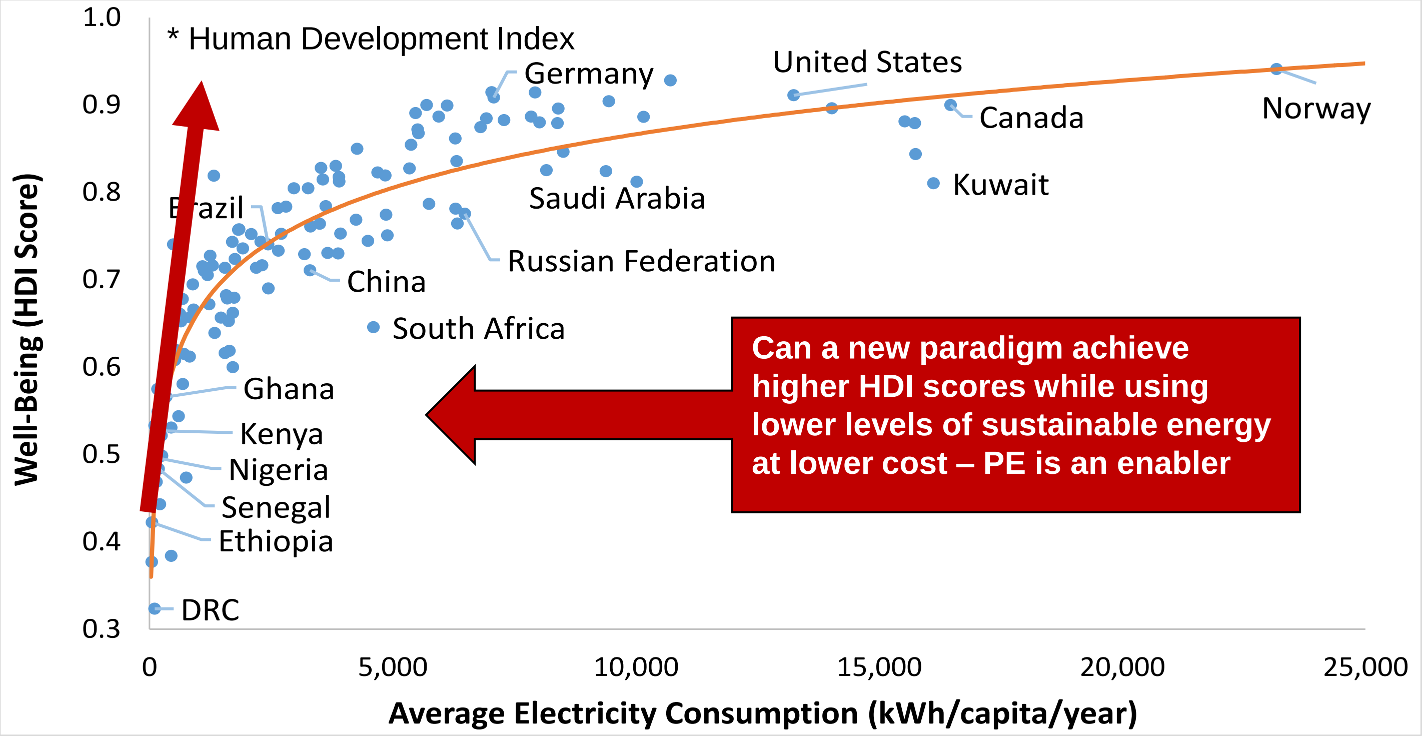
Key Messages:

- 3 billion live in extreme energy poverty, ~1 billion live off-grid (only 15 million have Tier 2 (>200WH/day)
- Solving energy access with today's solutions will result in 3.7 Gtons of CO2 emission – not OK
- Existing assumptions relying on grid extension and microgrids are not working out as expected

Challenges:

- **Don't need energy – need livelihood and services**
- Factors - low purchasing power, aspirations, neighbors
- Low-tech users, interoperability, tech-obsolescence
- Last-mile sale, commission and maintain challenges
- Scalable - start small & grow as needed
- Need flexible and sustainable business models.

IEEE Empower a Billion Lives (EBL) is an interdisciplinary, biennial global competition to identify and promote innovative solutions to energy poverty.



"…almost half of consumers are currently using less than 20 kWh per month … when a consumer would need to use approximately 130 kWh per month in order to fund the cost of their own connection…"

- Rwandan Rural Electrification Strategy, 2016

Mini-grids' relatively expensive electricity is mostly used only for lighting and mobile phone charging, if consumers use it at all.

Early Announcement: EMPOWER A BILLION LIVES - II

Building on the success of Empower a Billion Lives - I, IEEE Power Electronics Society is pleased to announce the second **Empower a Billion Lives – II,** global competition to be held from August 2021 to October 2022. Please visit www.empowerabillionlives.org for further information on joining the EBL community or to participate as a team.

You are invited to join us in a virtual webinar/workshop being organized by IEEE PELS to get inputs and to build a global community, to explore ways in which IEEE can help, and to build a community to support EBL-II.




Virtual Workshop on Energy Access and Empower a Billion Lives II (EBL-II)

Accelerating Deployment of Viable and Sustainable Energy Access Solutions at Scale

June 30, 2021 8:00 am – 12:30 pm EST

Attendees: World Bank, IFC, ESMAP, GOGLA, SE4ALL, IRENA, IEEE PELS, CSS, ISV, PES etc.

Register for Webinar & Workshop

organized by

IEEE Power Electronics Society (IEEE PELS)

pels IEEE POWER ELECTRONICS SOCIETY

IEEE EMPOWER A BILLION LIVES *An IEEE-PELS Initiative*

IEEE PELS launched IEEE Empower a Billion Lives (EBL-I) in 2018 as a recurring global competition for teams to develop and demonstrate scalable solutions to energy access. Over 450 teams from 70 countries responded. Five regional competitions (China, India, Africa, Europe and US) and field demonstrations in Rwanda, Uganda, Malaysia, Nepal, Madagascar, India, Tanzania, China, Nigeria, Cambodia, Singapore, Kenya & Ivory Coast with a global final in Baltimore in Oct 2019.

Solutions presented by the teams included microgrids, nanogrids, solar home systems, improved business models, and appliances. Over $500,000 was provided in awards and team support, including a $100,000 Grand Prize to team SoULS from IIT Bombay. Other global winners include XPower, Reeddi, Entrepreneurs du Monde and Okra, SolarWorx and Havenhill Synergy.

Conclusions

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- **VISION:** A future grid that realizes reliability and resiliency from the grid edge, and access to low-cost energy from the bulk power system, when it is available
- One key element to achieve this goal is a flexible plug-n-play power-brick which addresses the needs of off-grid communities, such as the Navajo Nation, as well as community resiliency after an HILF event
- The 1.25 kW, 1 kWh AC Cube module provides such a building block and supports most residential loads, and multiple modules can be connected in parallel to increase output power and run time.
- The AC Cube eliminates the need for skilled technician install and operation through a plug-n-play design, use of advanced collaborative controls, and intrinsic electrical safety.
- The proposed universal control scheme enables both stand-alone and grid-connected applications, enabling a variety of system installation possibilities in resiliency and contingency scenarios.