CHANGING WHAT'S POSSIBLE

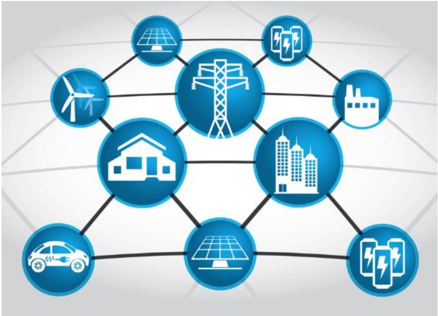
Packetized Energy Management

Coordinating Transmission and Distribution

Mads Almassalkhi (PI)
Assistant Professor / Co-founder
University of Vermont / Packetized Energy

Network Optimized Distributed Energy Systems (NODES)
Annual Review Meeting

Feb 13, 2019



E pluribus unum

Technical team

Mads Almassalkhi

Jeff Frolik

Paul Hines

Sumit Paudyal

Luis Duffaut-Espinosa

Mahraz Amini (PhD, UVM)

Micah Botkin-Levy (MS, UVM)

Adil Khurram (PhD, UVM)

Dr. Guna Bharati (MTU, Opal-RT now)

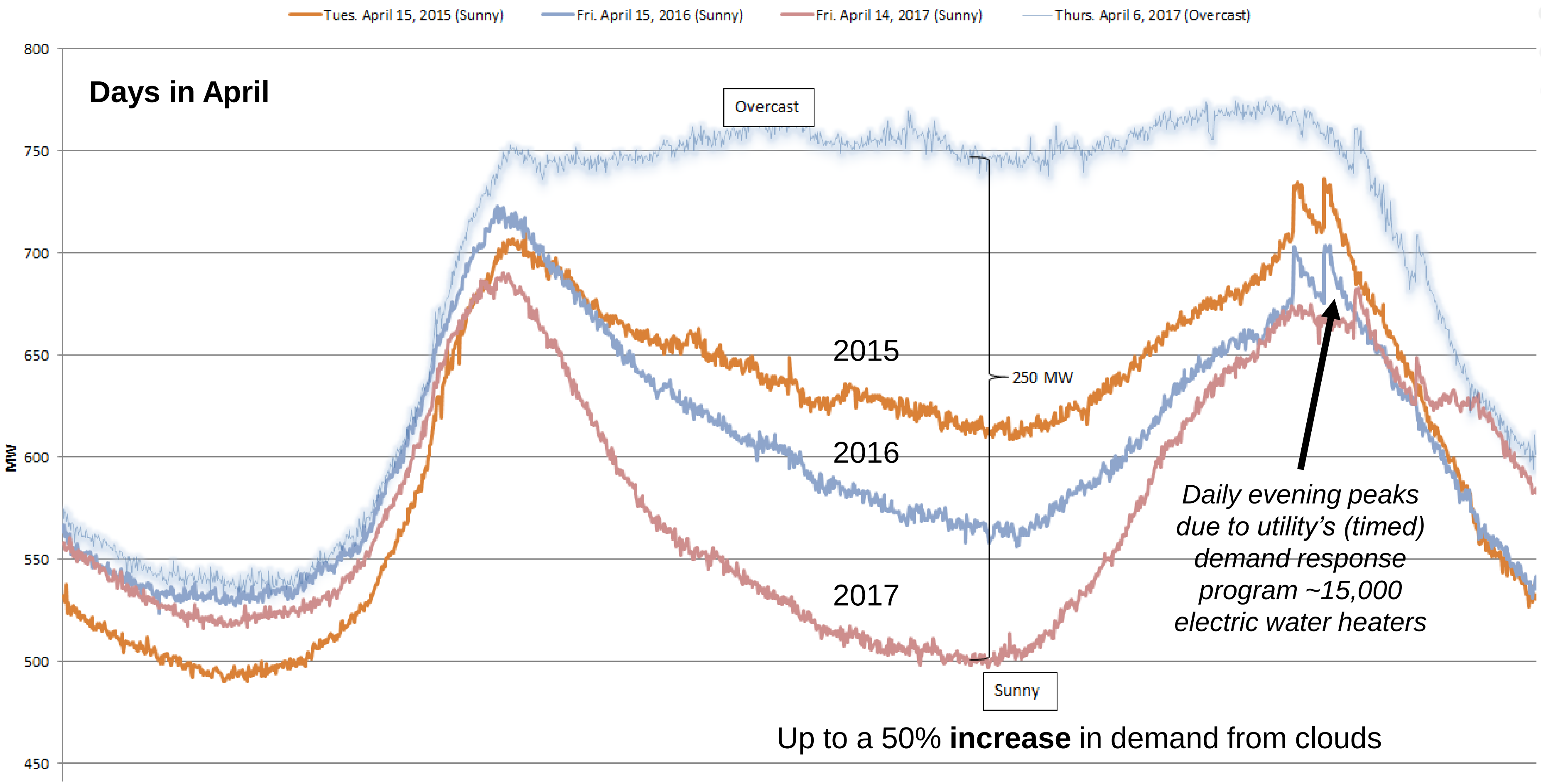
Dr. Jingyuan Wang (MTU, ETAP now)

Optimization | Communications | Power | Controls

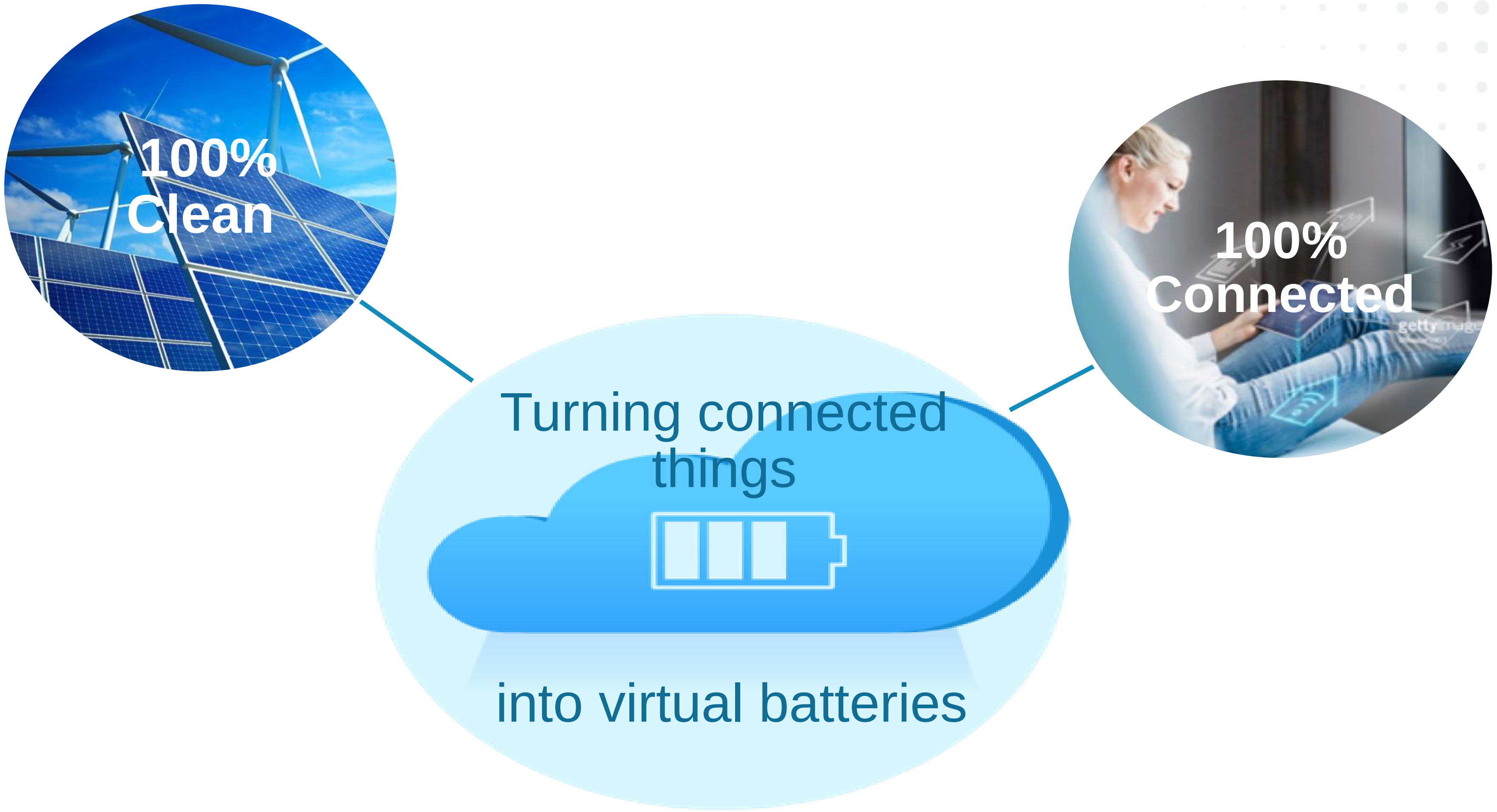
Validation partners

T&D | SaaS | IoT

Renewables are coming, even in Vermont



Connecting trends



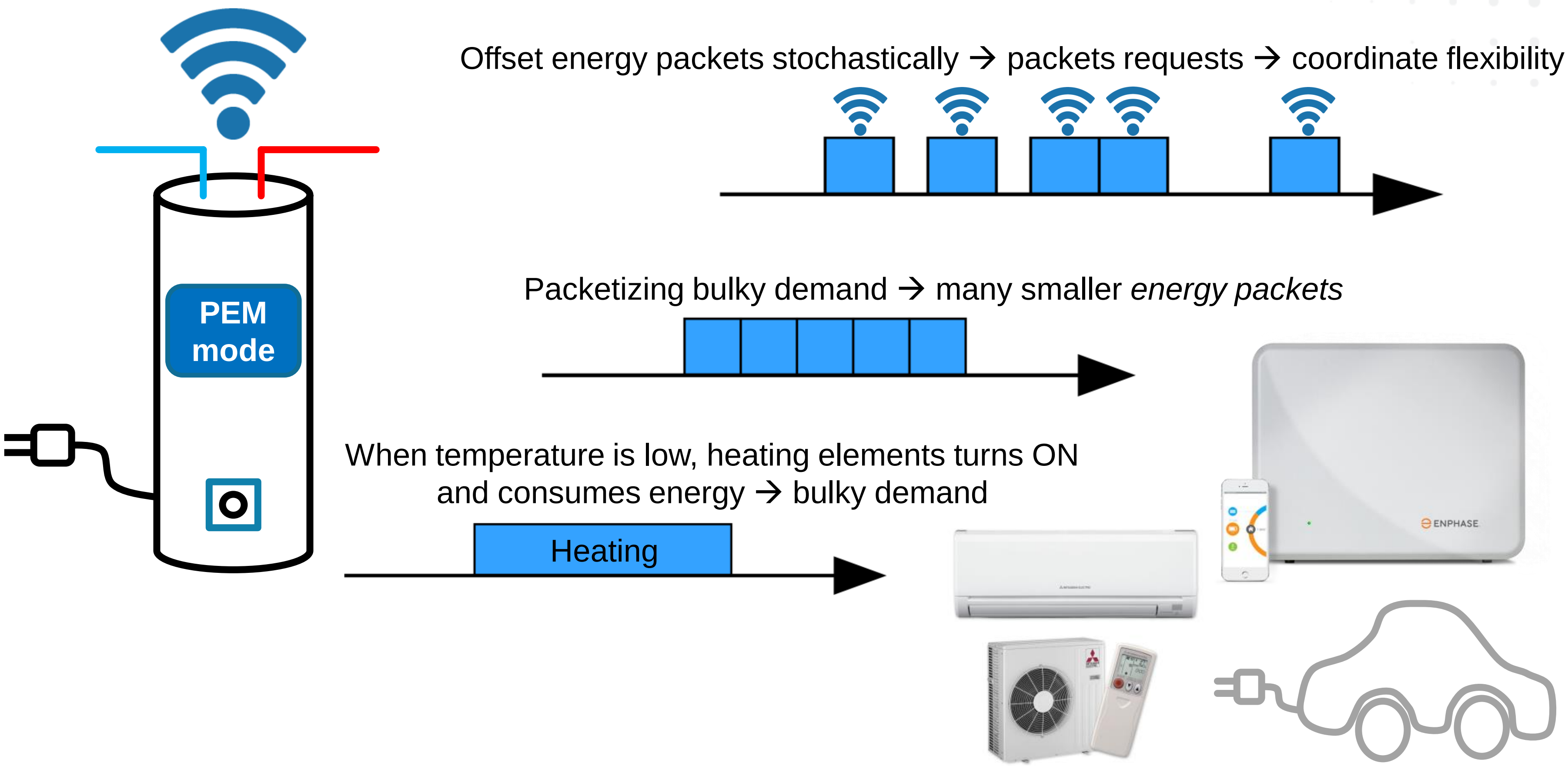
Leverage key tools to coordinate at scale

Packetization

Randomization

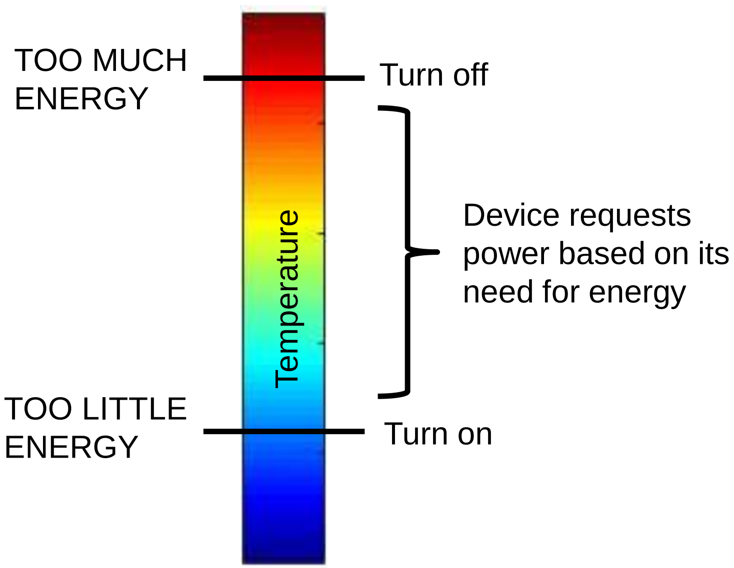
Packetized Energy Management: DER

Energy packet = constant power consumed over fixed epoch = ☐



Packetized Energy Management: DER

Take a DER that has stored energy and occasional usage



Great need for energy

► More frequent requests

Less need for energy

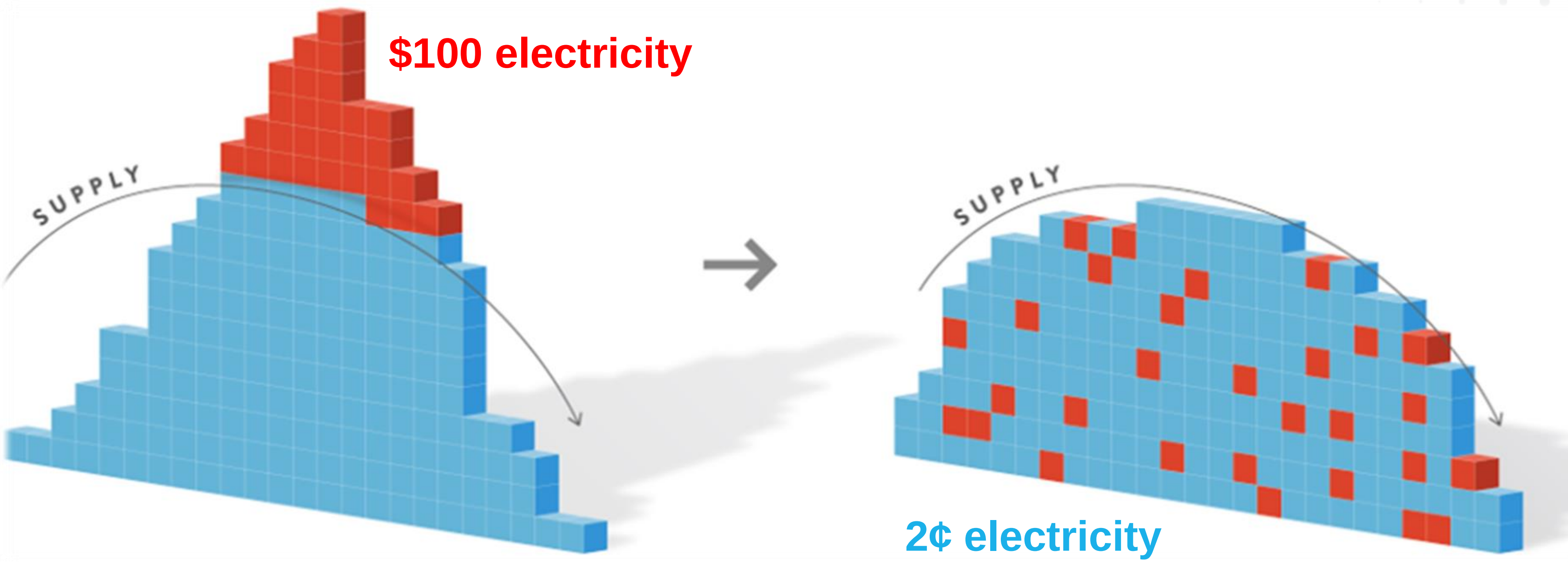
► Less frequent requests

Too little energy

► Just run to make sure people get the energy they need (“temporary opt out”)

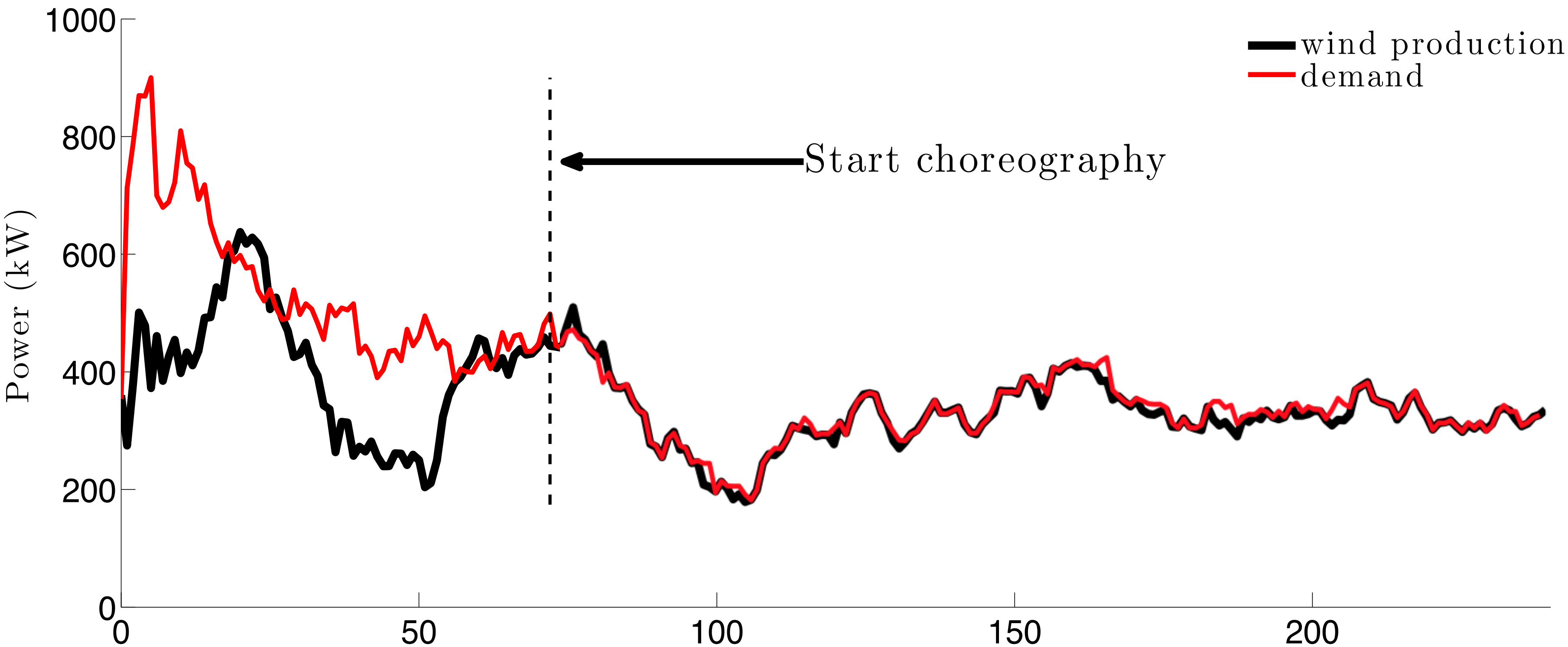
Guarantees QoS!

Packetized Energy Management: Fleet



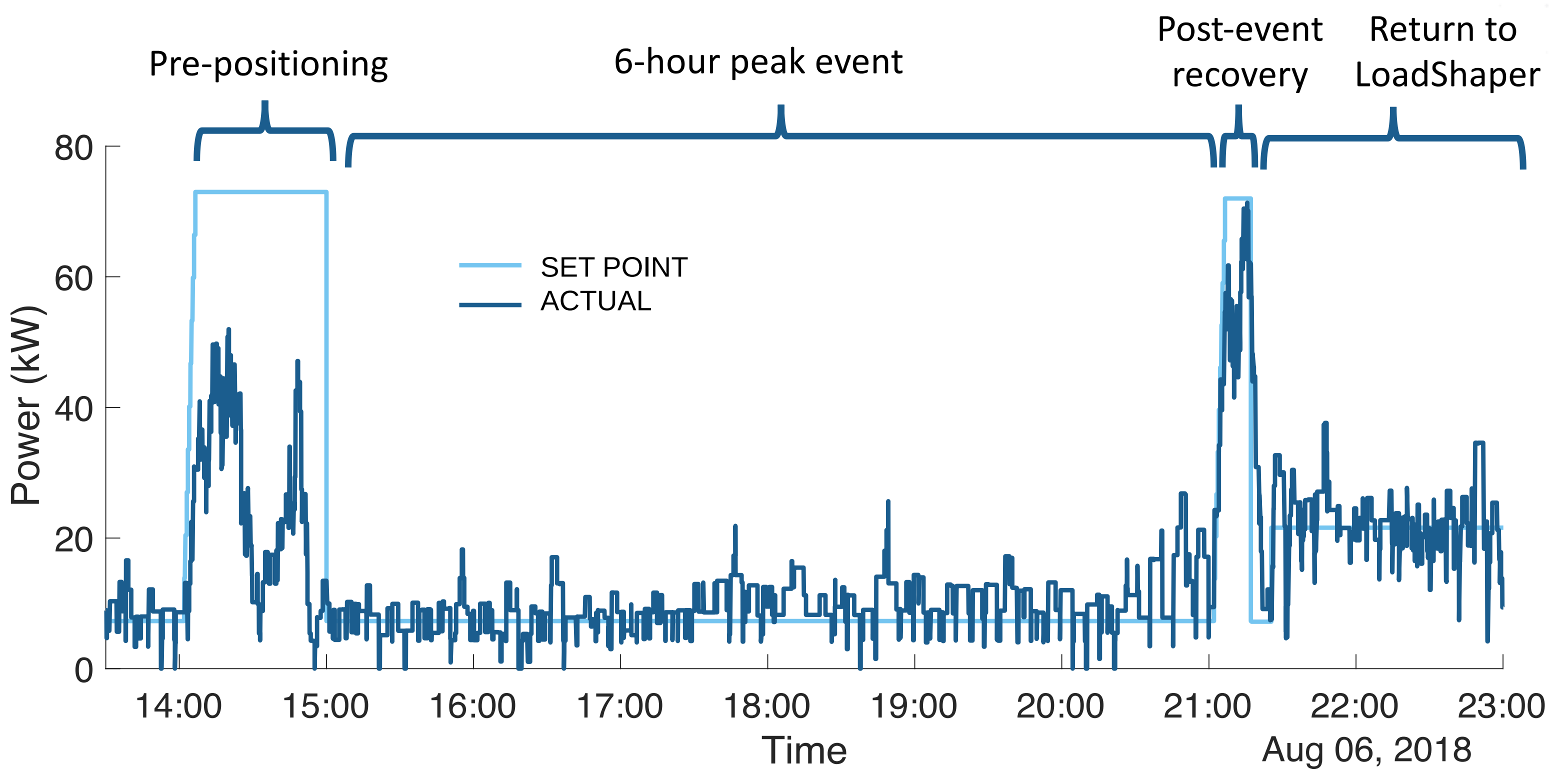
And it works really well

Example simulation with 300 packetized water heaters



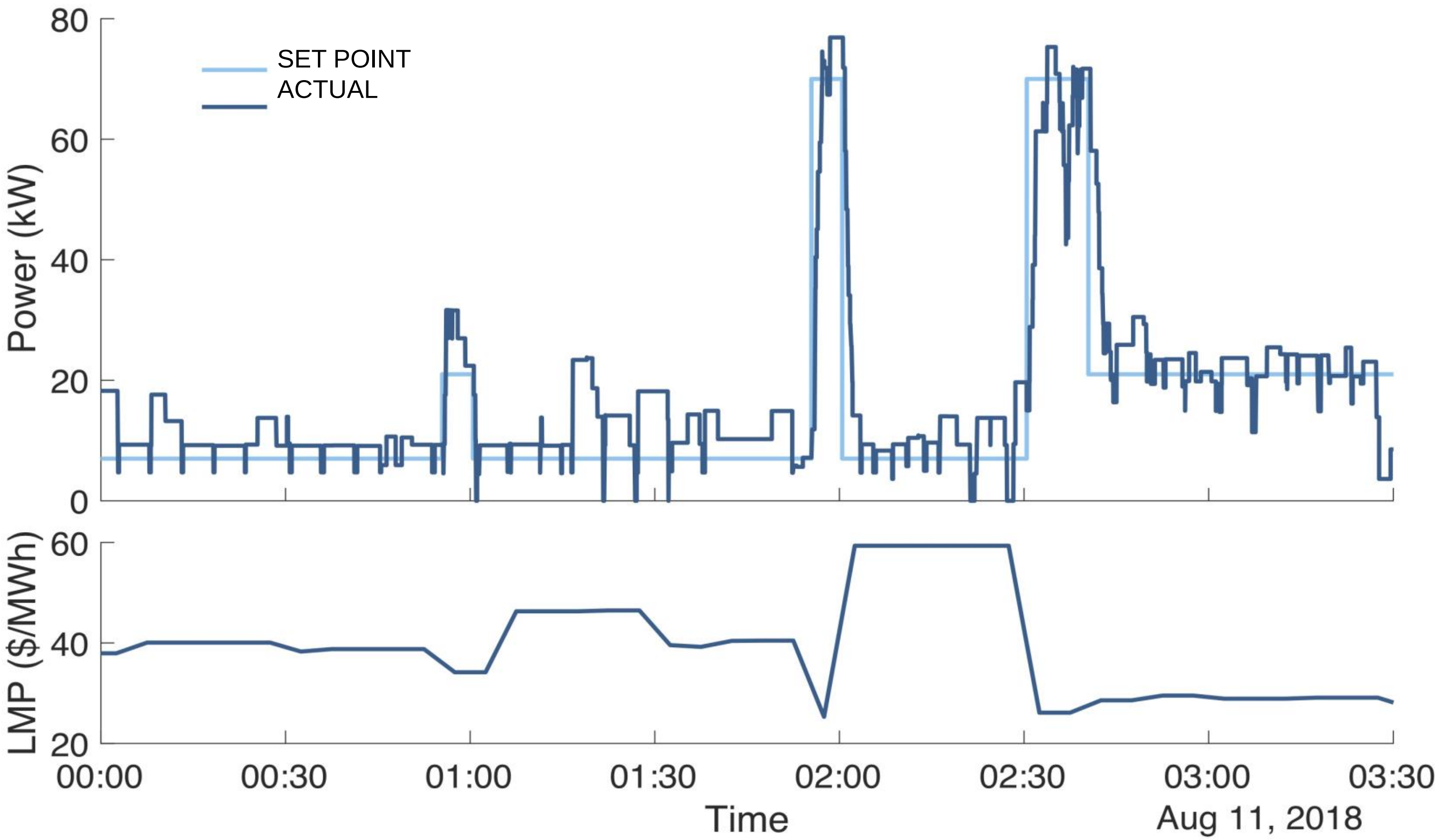
300 5-kW water heaters choreographed by PEM to track with 350±150kW of renewable generation **in real-time**

Also in the real world (crushing peaks)



ABOUT 60 WATER HEATERS, VERMONT ELETRIC CO-OP (raw kW data)

Also in the real world (arbitraging)



ABOUT 60 WATER HEATERS, VERMONT ELETRIC CO-OP (raw kW data)

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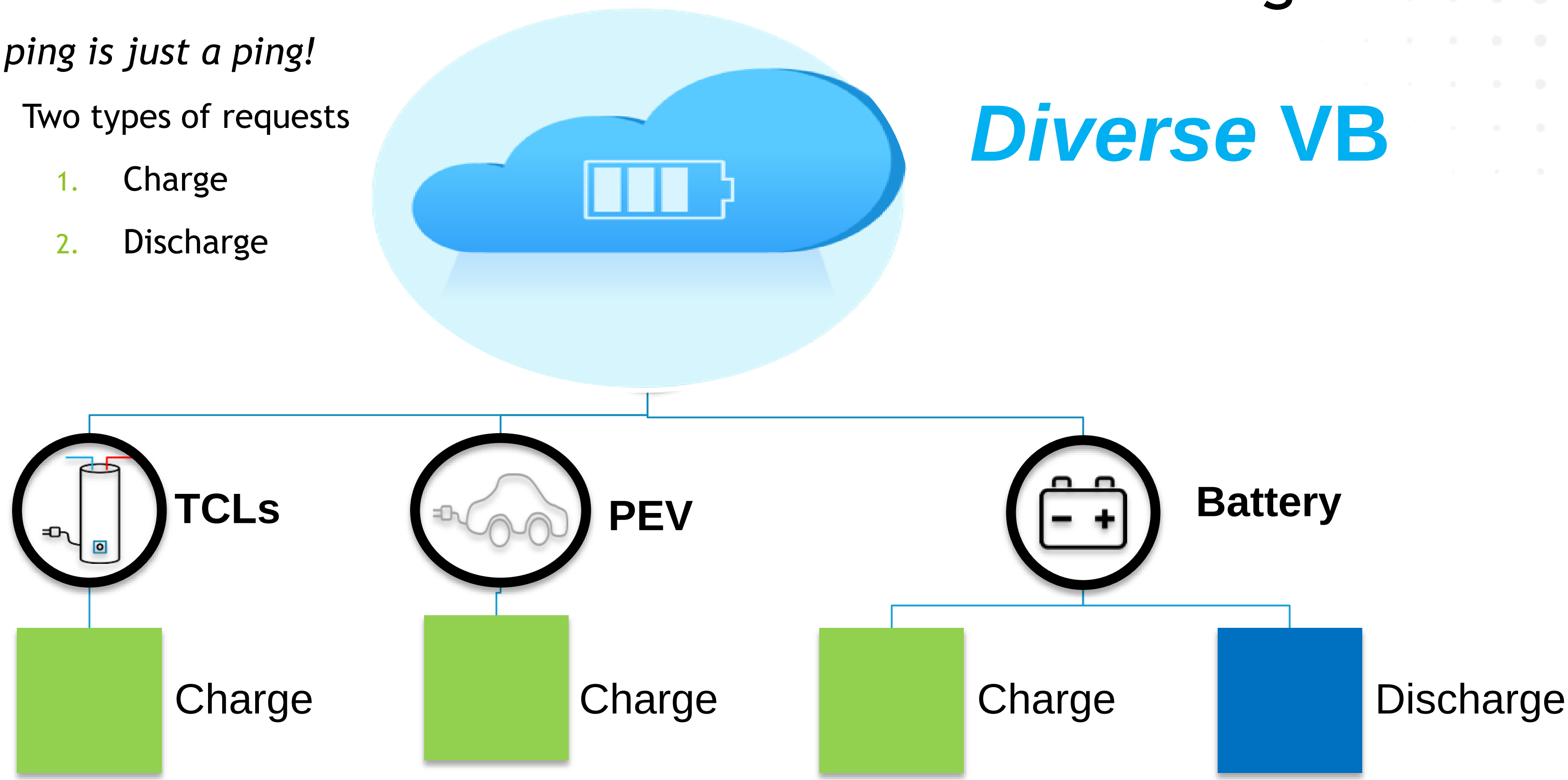
More than just water heaters

PEM can coordinate *diverse* DERs under single VB

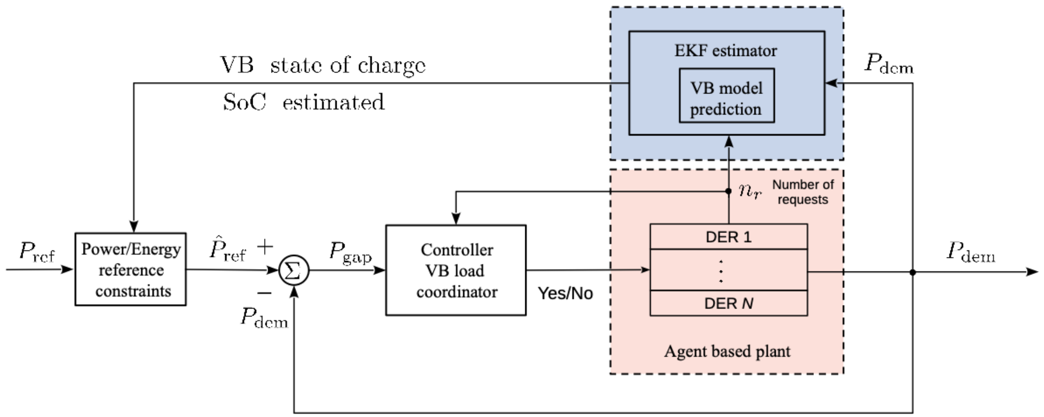
A ping is just a ping!

- Two types of requests
  1. Charge
  2. Discharge

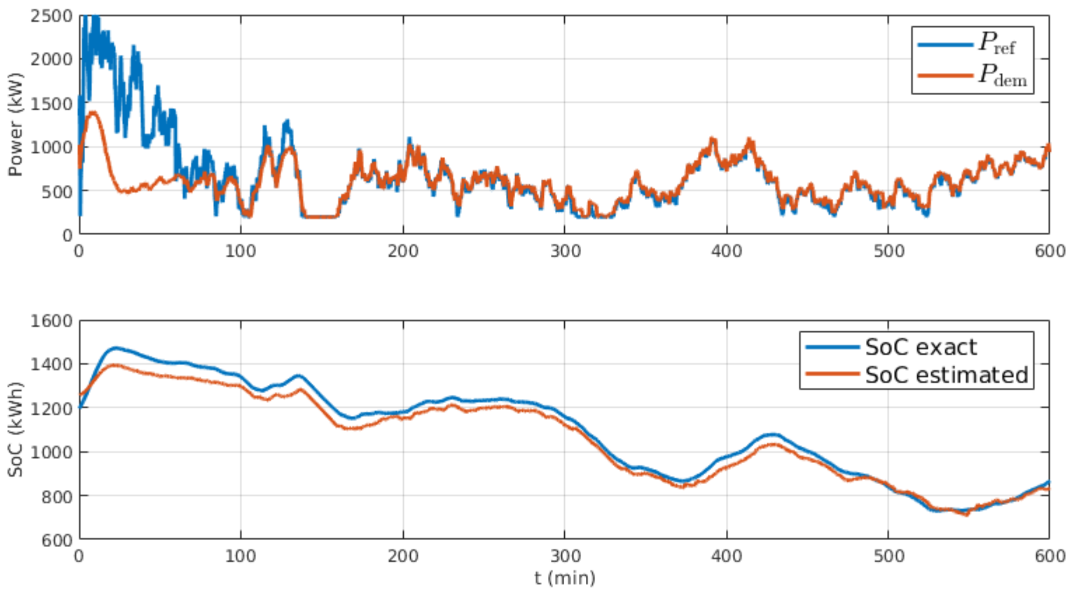


A single VPP coordinates requests from diverse types of DERs!

Infer state-of-charge of VB

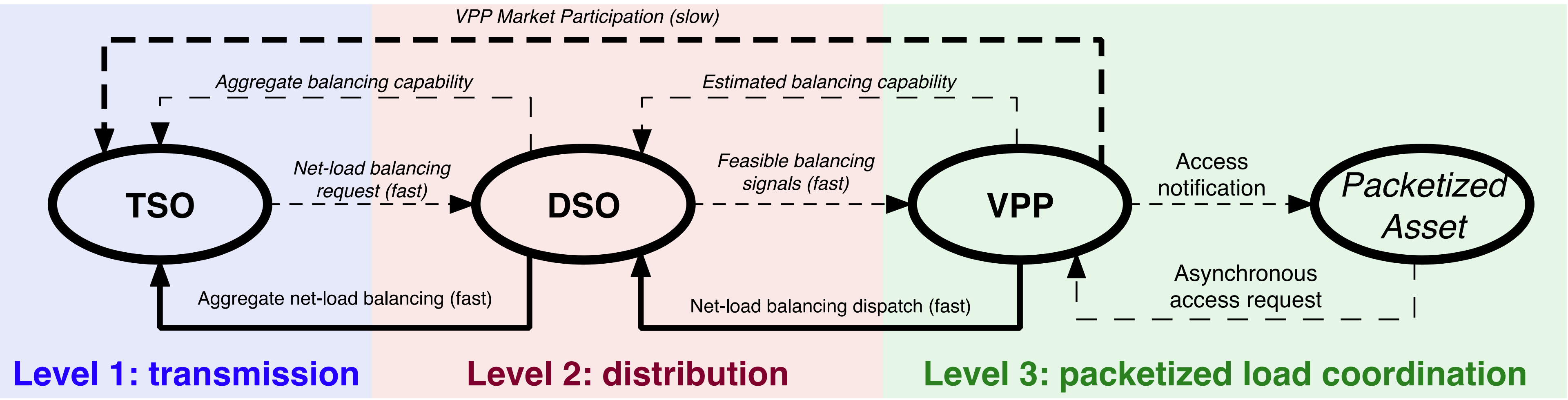


Only needs total number of requests and total demand per 15s interval as inputs (2 data pts).



Project approach

- **Bringing technologies together**
  - *Packetized Load Coordination* (patented) is scalable, privacy-aware, fair, and plug-and-playable.
  - *Model-Predictive Control* will manage uncertainty in available renewables and packetized loads to balance net-load in T&D in receding horizon fashion.



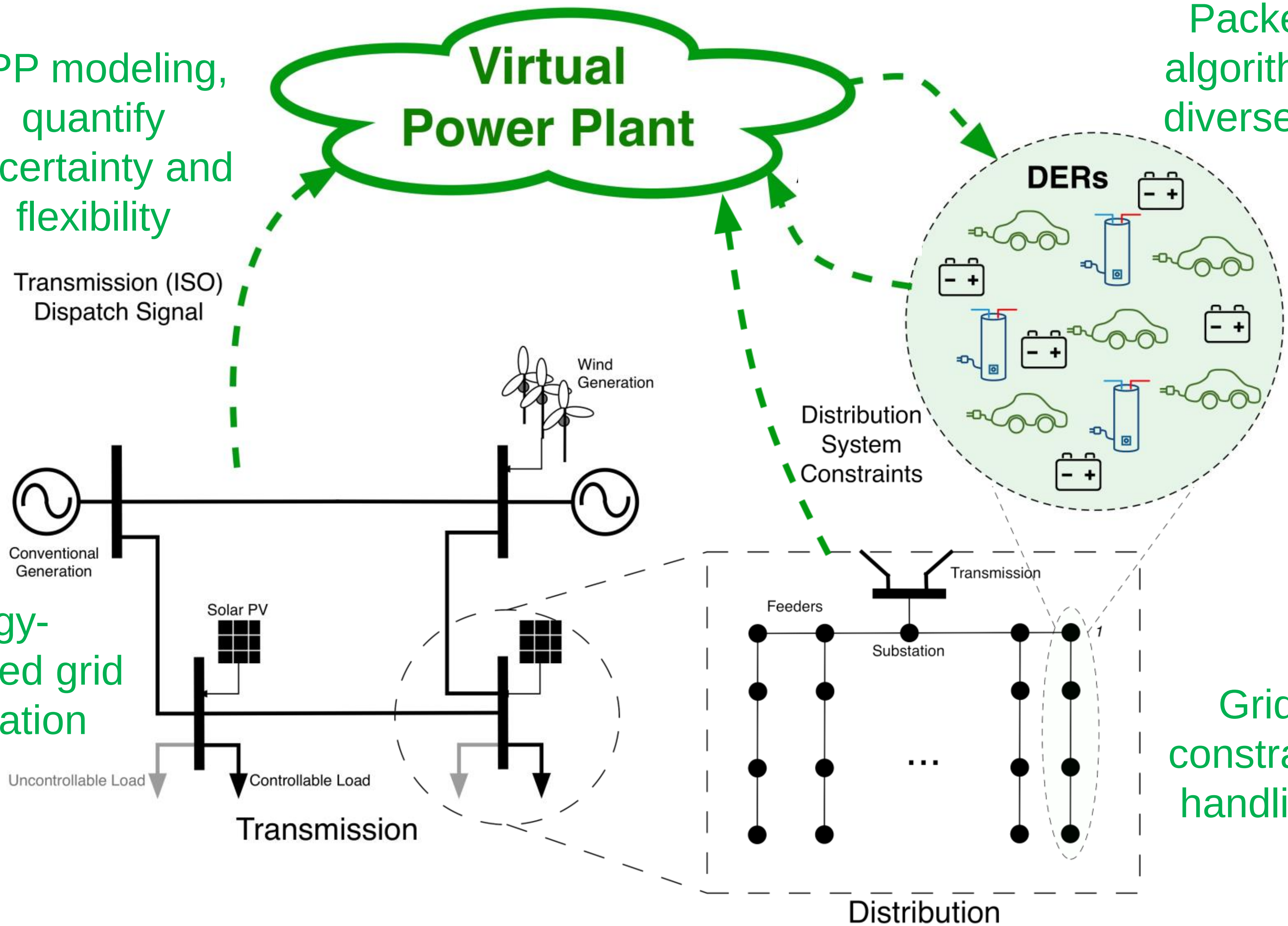
Project goals

VPP modeling, quantify uncertainty and flexibility

Packetized algorithms for diverse DERs

Energy-constrained grid optimization

Grid constraint handling



Project Progress

Year 1: technical developments

T&D modeling, optimization, control
- Hourly realizable reference trajectories
- Min-by-min AGC-like balancing signals

VPP tracking and inference
- Quantify uncertainty, tracking performance, communication needs

Packetized asset automata design
- e.g., TCLs, Evs, BESS

Year 2: initial hardware validation and uncertainty

Uncertainty in VPP for T&D
Chance-constrained optimization

Validation with HiL Simulations
Small-scale complete; larger scale complete

Year 3: final validation and demonstration

Large-scale realistic simulations

Utility demonstration with > 100 hardware devices

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Validation Plan (HIL)

Level 3: Virtual Power Plants (VPPs)

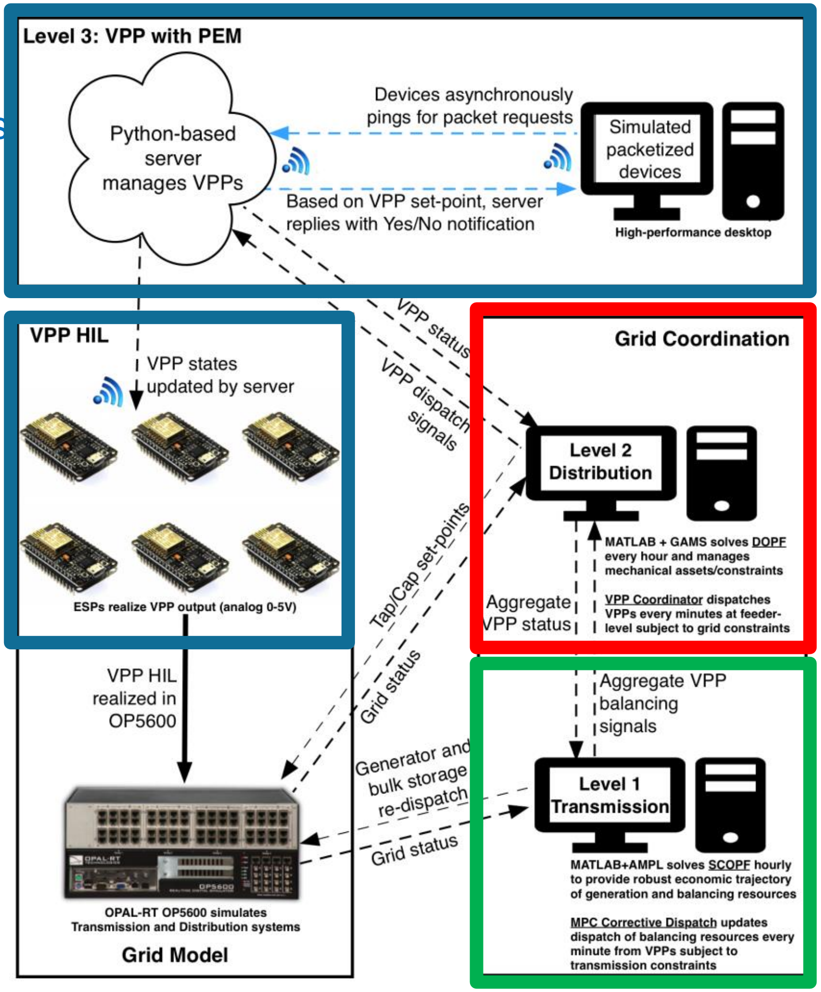
- Packetized devices are implemented in software on PC and aggregated into local VPPs
  - ESPs are physical realization of VPP
- VPPs are implemented on server and communicates with Level 2 and ESPs over WiFi

Level 2: Distribution System Operator (DSO)

- DSO measures VPPs' local feeder/Xfmr flows and updates each VPP's target values.

Level 1: Transmission System Operator (TSO)

- DSO aggregating its local VPPs; updates TSO
- TSO determines balancing need and communicates with Level 2 (DSO) via MATLAB



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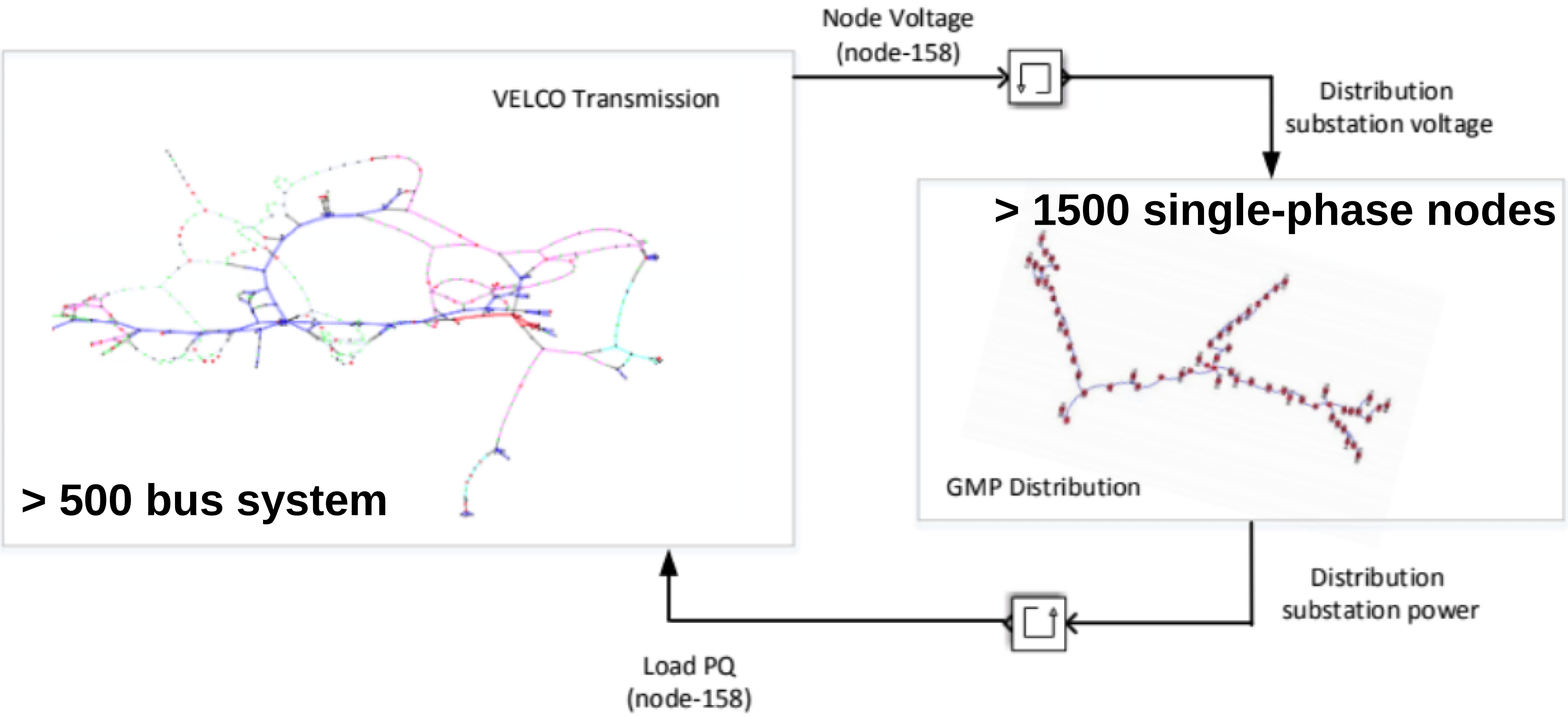
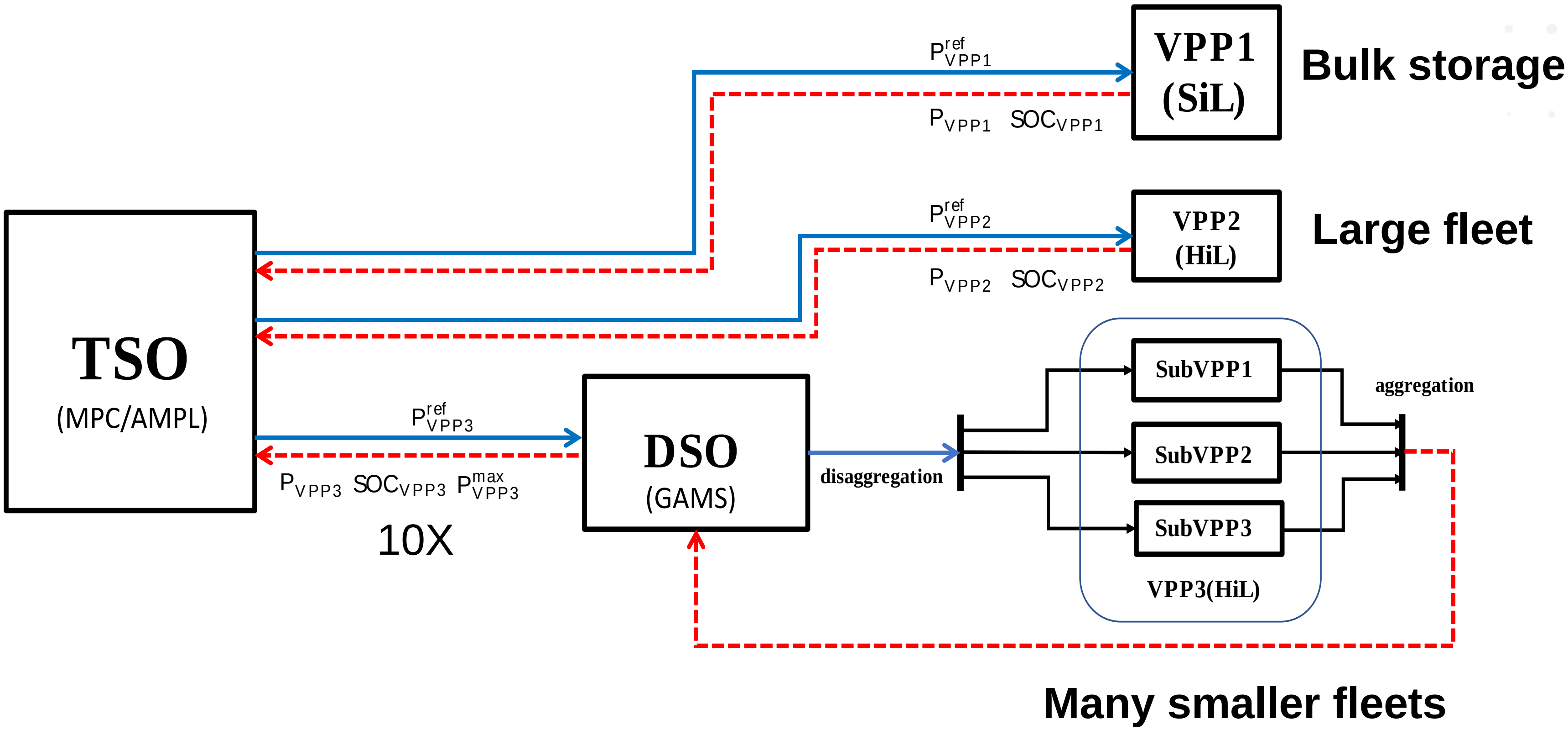
Validation plan (HIL)

- Major Tasks Completed
  - HIL Implementation of Transmission and Distribution (T&D)
    - Decoupled Approach



HiL experiment setup: VPP specs



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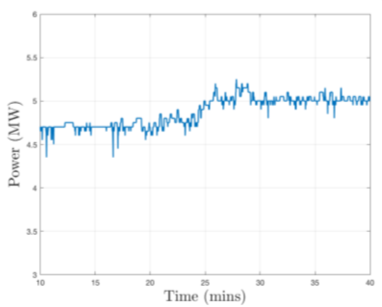
TSO-DSO-Fleet

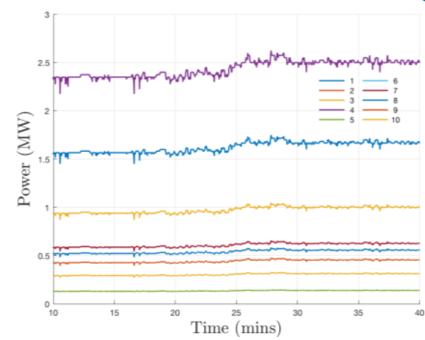
TSO computes VPP balancing control signals to DSO



Transmission System Operator (TSO), Level 1				
VEP (ID)	Target Power (MW)	Actual Power (MW)	Power Flex (MW)	Energy Flex (MWh)
1	5	5.13	5	8.2 MWh
2				
:				
N				

MATLAB and ePHASORSIM

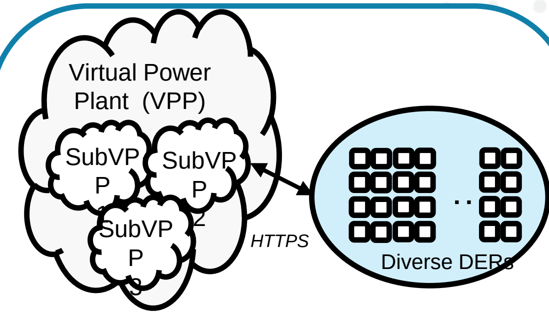
DSO disaggregates VPP signal into sub-VPP signals to fulfill VPP balancing requests



Distribution System Operator (DSO), Level 2					
VEC ID	VEP ID	Target Power (MW)	Actual Power (MW)	Power Flex (MW)	Energy Flex (MWh)
1	1	1.55	1.60	2	4.0
2	1	0.95	0.98	1.5	2.0
3	2				
4	1	2.5	2.55	1.5	2.2

HTTPS

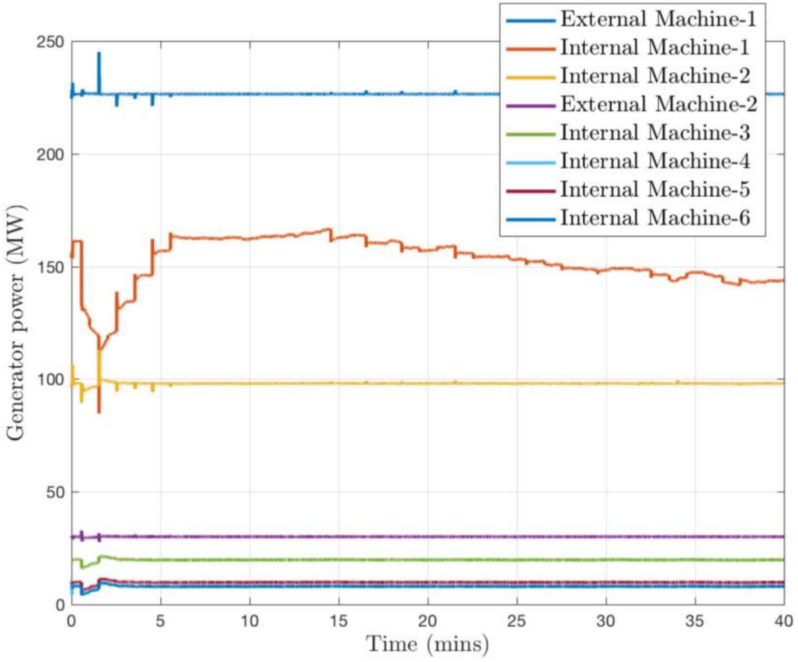
Sub-VPP accepts/rejects requests based on available local DER flexibility

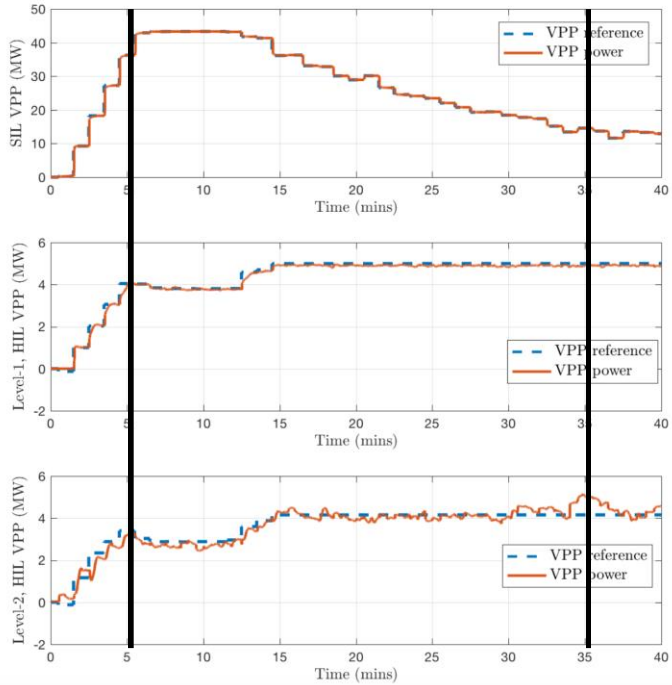


Sub-VPP with PEM, Level 3				
Dev ID	VEC ID	P_{rated}	Relay State	PEM State
100	1	5		ON
:	:			:
199	1	4.5		OFF
200	2	4		OPT-OUT
:	:			:
299	2	5		ON
:	:	:		:

Tracking with PEM (HIL)

- OPAL-RT's ePhasorsim + 9000 simulated DERs running on own clock and online server (as VPP)





Tracking RSME < 3%

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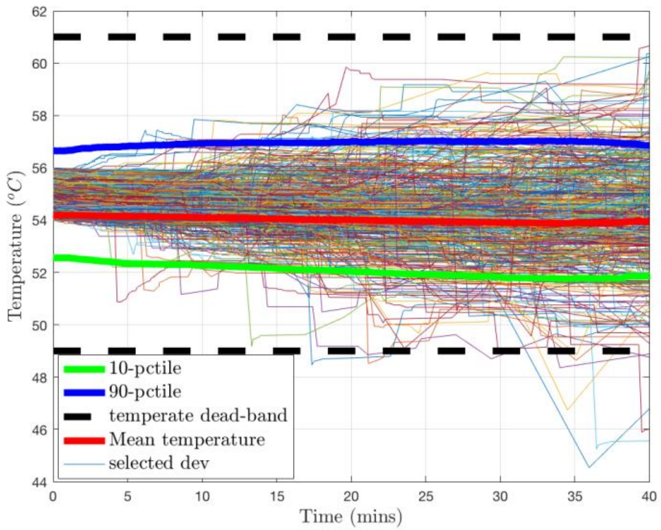
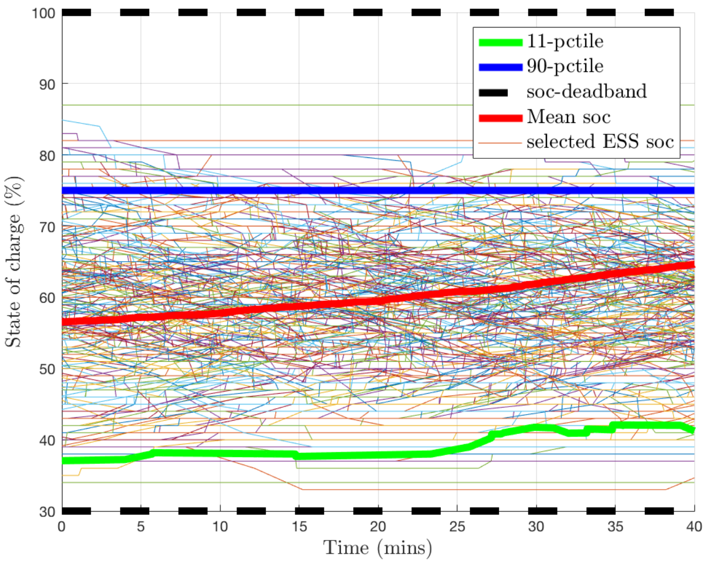
Tracking with PEM (HIL)

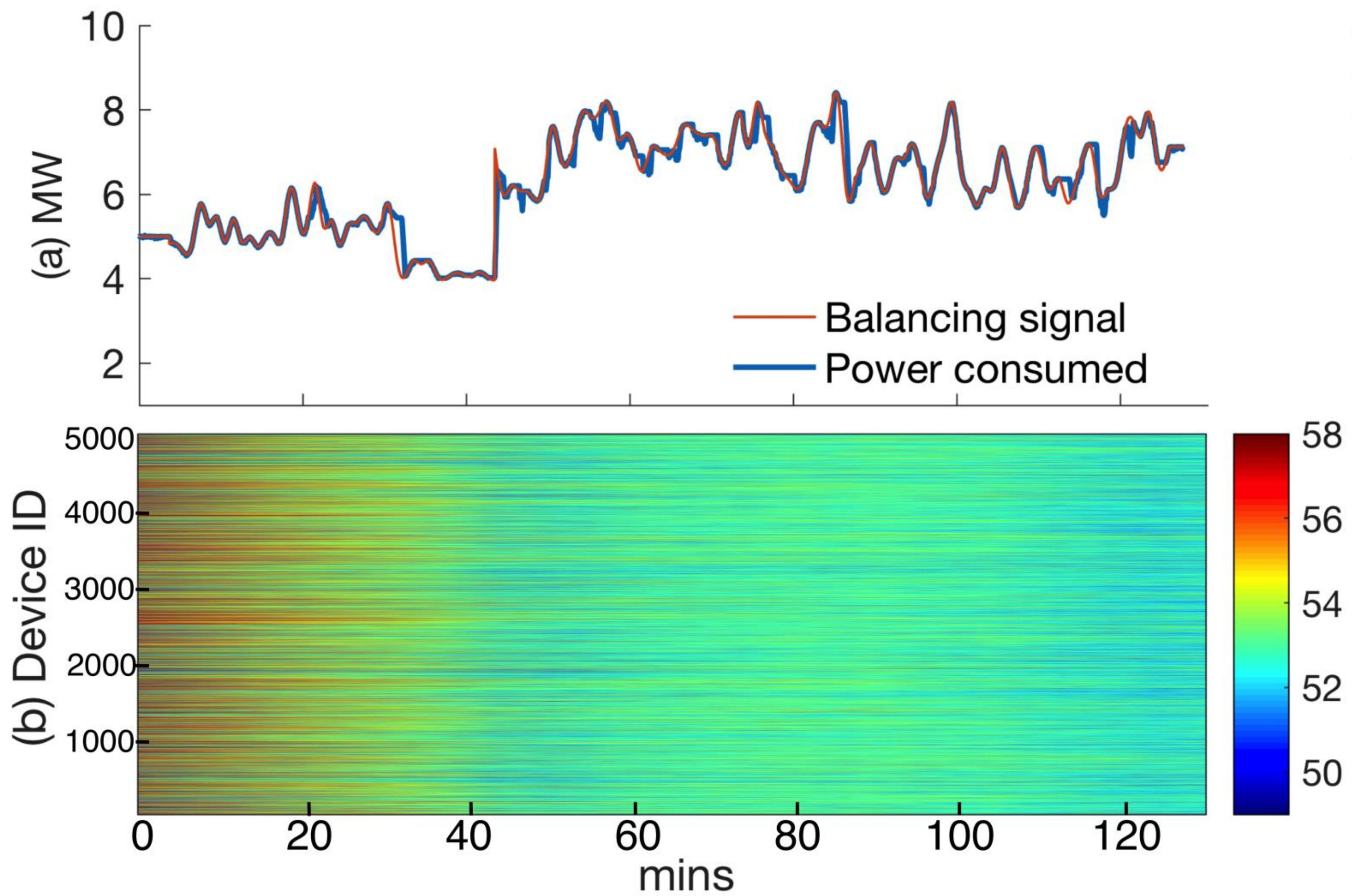
- Packetized water-heater QoS
- Packetized distributed batteries QoS





Pre-defined QoS is maintained

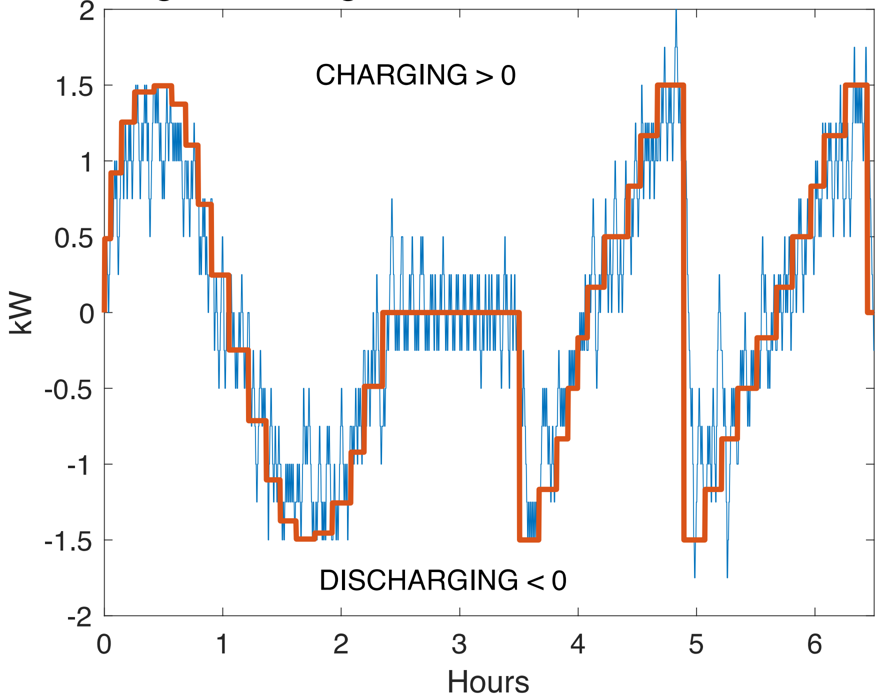
Tracking a stochastic signal (HIL)



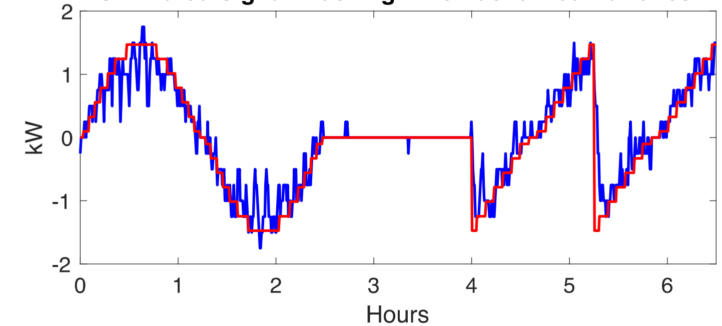
Tracking a periodic signal (HIL demo)

10 Enphase's AC Batteries packetized into VB

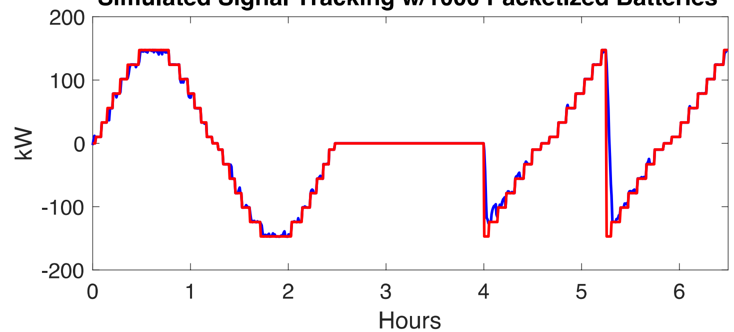
Signal Tracking w/ 10 Packetized 250W Batteries



Simulated Signal Tracking w/10 Packetized Batteries



Simulated Signal Tracking w/1000 Packetized Batteries



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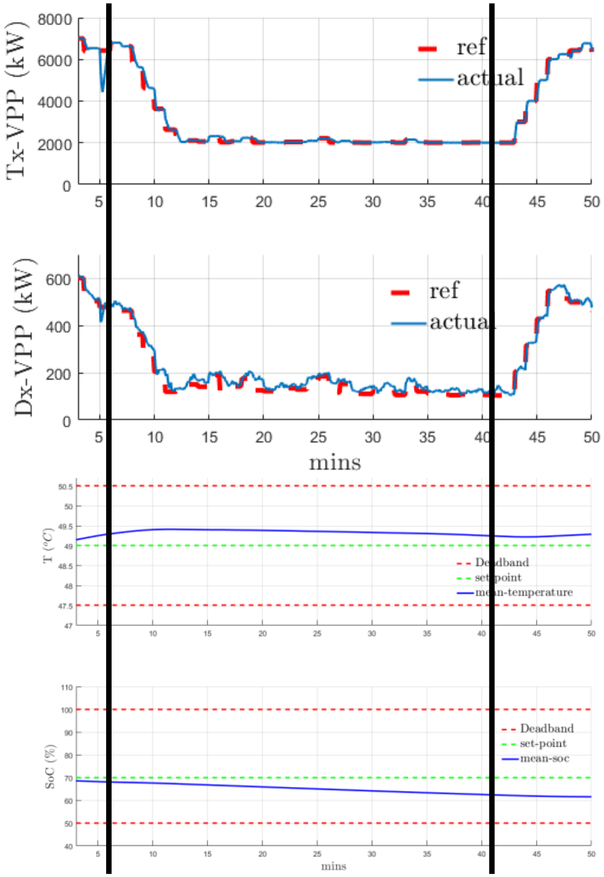
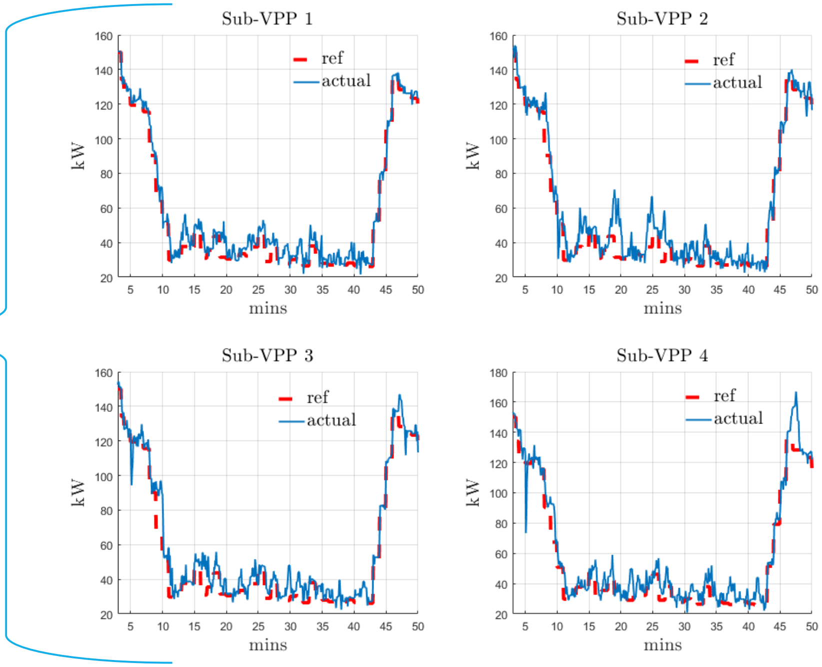
Tracking with PEM (Large-scale sim)

Tracking with 9000 (Tx) & 1000 (Dx) devices

QoS





Aggregation is valuable

Tech to Market Path and IAB

arpa·e awardee

Network
Optimized
Distributed
Energy
Systems

NSF | America's SEED FUND SBIR.STTR

SLAC

Michigan Technological University 1885

UTILITY PARTNERS

- Green Mountain Power
- Burlington Electric Department
- Vermont Electric Co-op
- PNM
- Consumers Energy — Count on Us
- Xcel Energy
- conEdison
- ATC American Transmission Company
- SMUD
- ISO new england
- Vermont Electric Power Company VELCO
- ITC

SOLUTION PROVIDERS

- Vermont Energy Investment Corporation
- IoT
- Dynapower Company
- OPAL-RT Technologies
- Schneider Electric
- infiswift
- Northern Reliability
- Adaptricity
- Webasto — Feel the Drive
- rainforest automation
- EnerNOC — An Enel Group Company
- opus one solutions
- Enphase
- greenlots

GOVERNMENT & POLICY

- Vermont
- Vermont Law School

TECH 2 MARKET

- Packetized Energy

IAB Future of Energy workshop held in Fall 2018

Workshop focus: flexibility, economics, and resilience of DERs

Conference call to be scheduled for April, 2019

Tech to Market Path and IAB

- Spin-off established in parallel to project (May 2016)
- Demonstrating & deploying NODES IP in the field
- Completed Berkeley/Haas C2M program.
- Completed Accelerate-VT program
- $350K seed investment round completed
- Awarded federal awards (>$500K) and more pending
- Raising pre-A/A round currently

Four **industry-funded pilot projects** ongoing

Burlington Electric Department	Green Mountain Power	Vermont Electric Co-op	PG&E / RHA
5-year Phase II project signed	150 packetized DERs with simulated live grid conditions	300 packetized water heaters, some batteries	Focused on resistive/heat pump water heaters to mitigate duck-curve effects
EWHs + EVs	EWHs + Batteries	Mostly EWHs	Dozens to 100s in Phase 1

Demonstration status with GMP

- GMP reached out to customers in Nov, 2018
  - Received 300 responses within 1 week!
- **Jan 30th, 2019: total of 76 devices allocated**
  - 20 devices deployed in homes already
  - 40 signed contracts to be deployed shortly
    - 24 of them at a single location (apartment building)
  - 16 customers sent contracts and installed once returned
- Another 74 devices need a home and we're working with GMP to ramp up marketing and outreach.
  - GMP has all Mellos already and expect good response
- Already have 8 packetized Enphase batteries (ACB1.0) and looking to acquire a few of their new batteries (ACB2.0)

Tech to market path

2013-2015

IP DEVELOPMENT

Initial R&D, first patent disclosure applied to EVs

2016

TECH ADVANCEMENT

$2M ARPA-E project, company founded, second patent disclosure, awarded first pilot

2017

CUSTOMER ADOPTION

Launched 2 new projects, UL listed smart device for water heaters, new DOE and NSF grants awarded

2018

COMMERCIAL VALIDATION & PARTNERSHIPS

Launching new projects in CA, new OEM partnerships, system deployment

2019

SCALING

Proving value, sales, moving from demonstration projects to full-scale deployment

CBINSIGHTS

"Game changing startups of 2019"

Tech to Market Path and IAB

DER coordination platform running with real hardware in the loop

Mello™
UL-listed smart thermostat for water heaters

Kate and Scott from PE at DTech

PoC solutions for connecting EV chargers and distributed batteries*, and more
**working prototype with* ENPHASE

Still to come: HVAC + Heat-pump

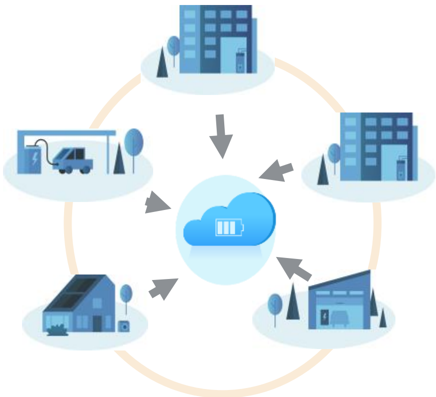
Deployment Programs
- Fuel switching enabling utilities to sell more clean electricity
- Marketing for rapid DER adoption

Virtual battery & physical battery

Battery designed to power 1000 homes for four hours (±1MW, 4MWh)

	per kWh	Total
Upfront cost	$ 450	$ 1,800,000
Ongoing O&M cost	$ 5/yr	$ 20,000/yr
Customer dividend	$ 0	$ 0
Present value cost	$ 481	$ 1,922,891

Equivalent Packetized Virtual Battery (2000 devices, ±1MW, 4MWh)



About half the cost of batteries <u>today</u> and getting better!

	Per device	per kWh	Total
Upfront cost	$ 200	$ 100	$ 400,000
Software	$ 30/yr	$ 15/yr	$ 60,000/yr
Customer dividend	$ 30/yr	$ 15/yr	$ 60,000/yr
Present value cost		$ 284	$ 1,137,348

Tech to Market Plan

Nimble™ virtual battery software platform

PeakCrusher. Advanced peak reduction tool. Pre-positions before events and adapts to real-time conditions to avoid cold/hot load pickup (**Online today at utility**)

“NODES Cat. 3”

LoadShaper. Automated energy arbitrage to minimize wholesale energy costs (**Online today at utility**)

“NODES Cat. 2”

FastTracker. Access ancillary service markets with fleets of grid-edge, packetized DERs & direct access to markets (in R&D)

“NODES Cat. 1”

GridSolver. Data-driven, real-time grid management to mitigating T&D CapEx and manage DERs within (local) physical constraints (In R&D)

Grid services

4 MODULES

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CHANGING WHAT'S POSSIBLE

Next steps

Spring 2019

- Help GMP finish deployment
- Get OpenADR up and running between UVM and PE
- Install and test a couple larger batteries

Summer 2019

- Complete GMP demonstration of > 100 diverse DERs
- Final report and benefit analysis

Future

- Extend PEM to faster time-scales (FastTracker)
- Incorporate live grid conditions into PEM (GridSolver)

Thank you! Questions? Comments?

Join us in Atlanta, GA!

Optimization Methods for Unbalanced Power Distribution Systems (2 NODES teams)	Chair: WSU
Enabling Advanced Grid Operations with DER coordination (5 NODES teams)	Co-chair: PNNL
Advanced Grid Architectures to support scalable DER integration (5 NODES teams)	Co-chair: SCE

Dates to be set shortly