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Active Power Filter for Smart Home — Enabling True Net Zero

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In collaboration with CIT2 and UCD

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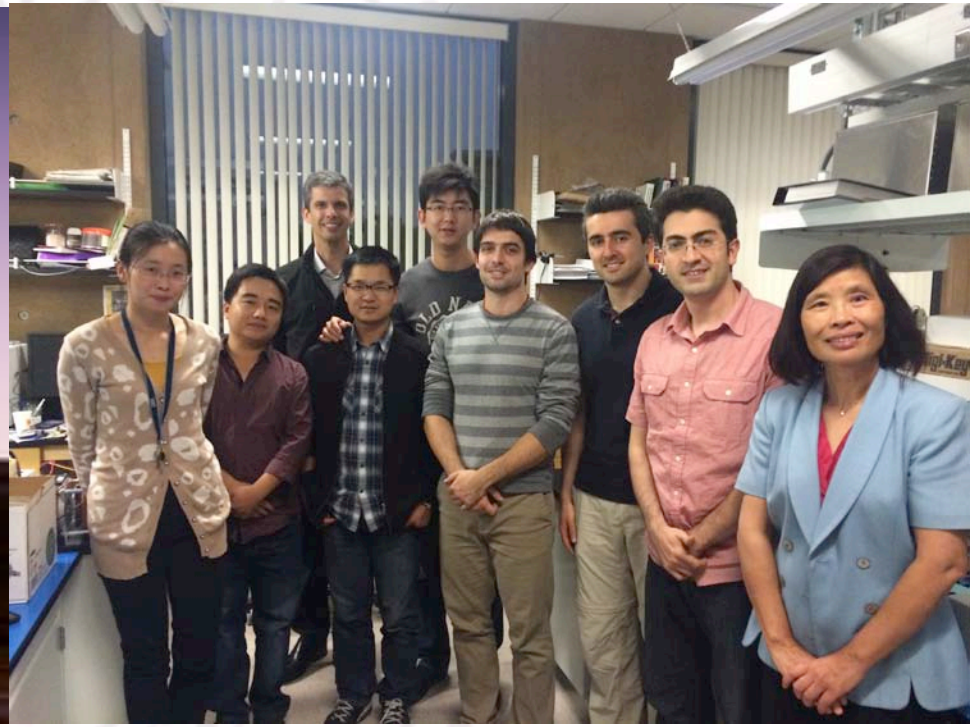

– Home of UCI Power Electronics Laboratory

Outline

- Power grid challenge and opportunity
- Smarter grid vision—home is a node
- APF makes grid smarter
- Field test result
- Power electronics enables energy super highway

The US Power Grid

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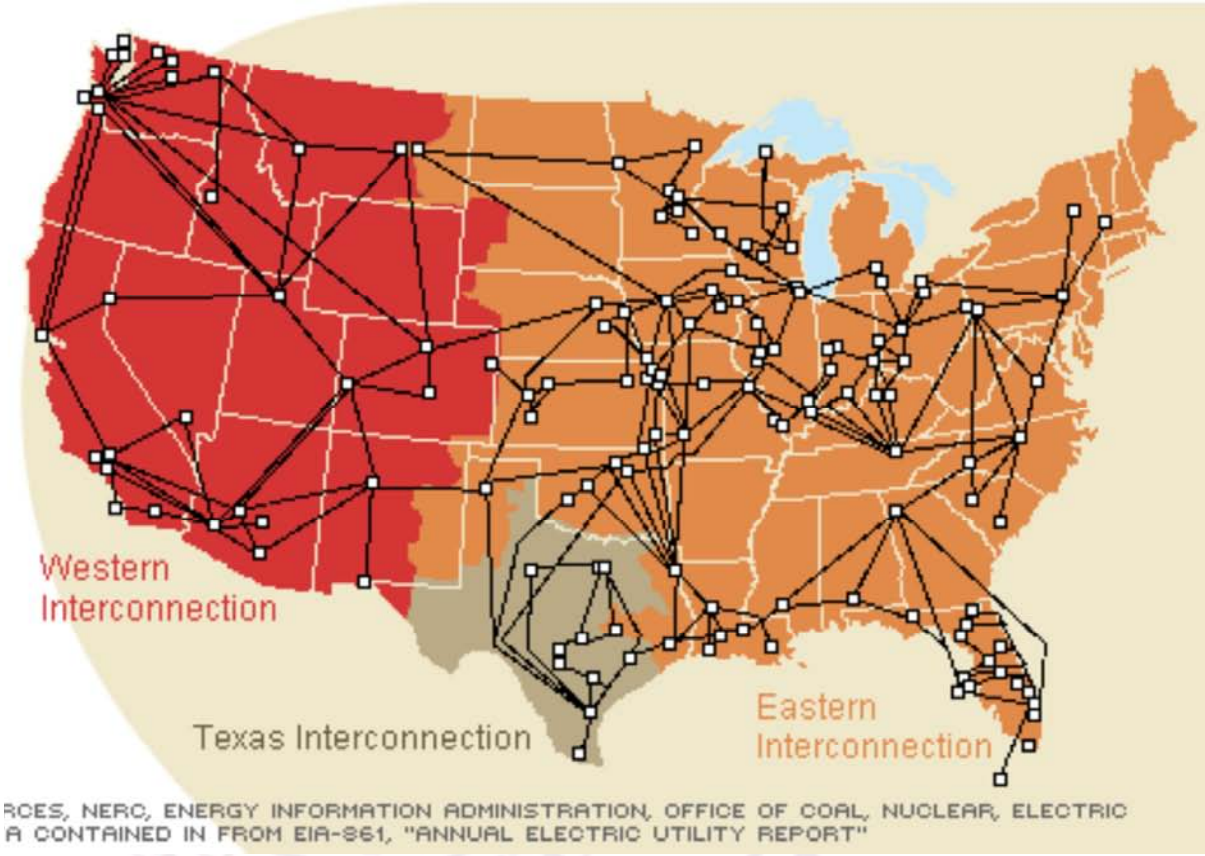
- 680,000 miles of transmission lines
- 5,000,000 miles of distribution lines
-made of L, C, R, transformer, switches, etc.
- with multiple inputs, multiple outputs
- obeys all electric circuit laws



One of the largest machines made by mankind.

Power Electronics is a key

- Grid connection
  - Solar: dc/ac
  - Wind: ac/dc and dc/ac
  - Both: MPPT
- Power balance
  - Energy Storage: Bidirectional ac/dc
  - Power flow control: Dynamic VAR compensation
- Reactive demand
  - VAR STATCON
- Power Quality
  - PV firming, wind stabilization: Energy storage
  - Dynamic VAR compensation

Smart-grid Vision-Control System with multiple input/output

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Photo: courtesy of http://www.isorto.org

Control system components:

- 2 way communications
- Sensors
- Controllers
- Actuators (power electronics)

Control strategy:

- Global set point control
- Local autonomous reflexes
- Information collection
- Islanding if grid is under attack
- Self healing

Power Electronics

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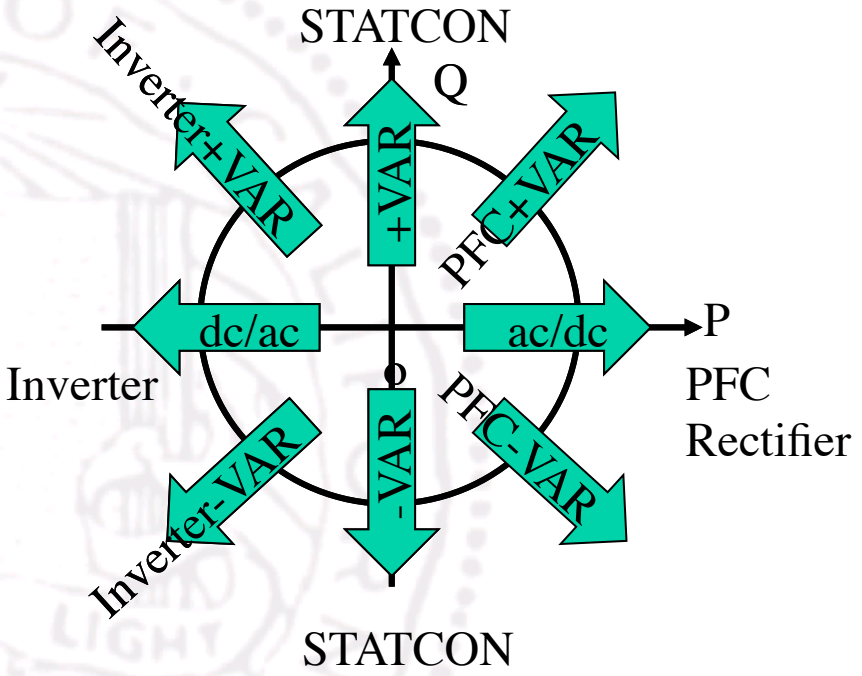
- Silicon has revolutionized IT. It is time to siliconize our power system[1].
- 4-quadrant power converter[2,3] => universal grid control actuator
- Fast precise control => local autonomous reflexes



1. Keyue Smedley, "One-Cycle Control and Its Applications in Distributed Generation" COBEP 2004, Brazil.
2. K. Smedley and C. Qiao, Unified Constant-frequency Integration Control of Three-Phase Rectifiers, Inverters, and Active Power Filters for Unity Power Factor, US Patent filed 9/99, 6297980. 2001.
3. Taotao Jin and Keyue Smedley, "T. Jin, L. Li, and K. Smedley, Universal OCC Converter for Distributed Generation, Power Electronics Technology Conference, Chicago, 2004.

One-Cycle Control Concept

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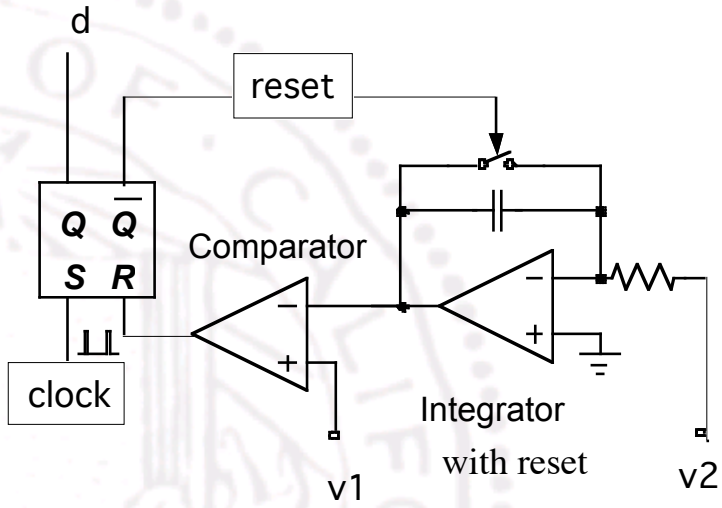
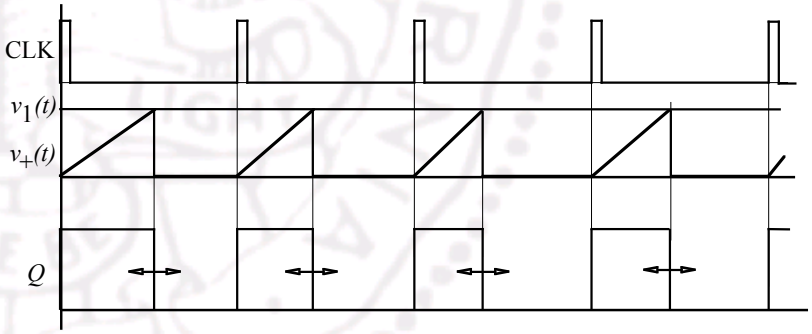
$$1/T_s \int_0^t V_2 dt = V_1$$
$$t = dT_s$$

$$V_2 d = V_1$$

- OCC solves the first order polynomial equation

- OCC solves most power electronic problems





K. Smedley "control art of switching converters" Caltech Ph.D.Thesis, 1991

Universal OCC

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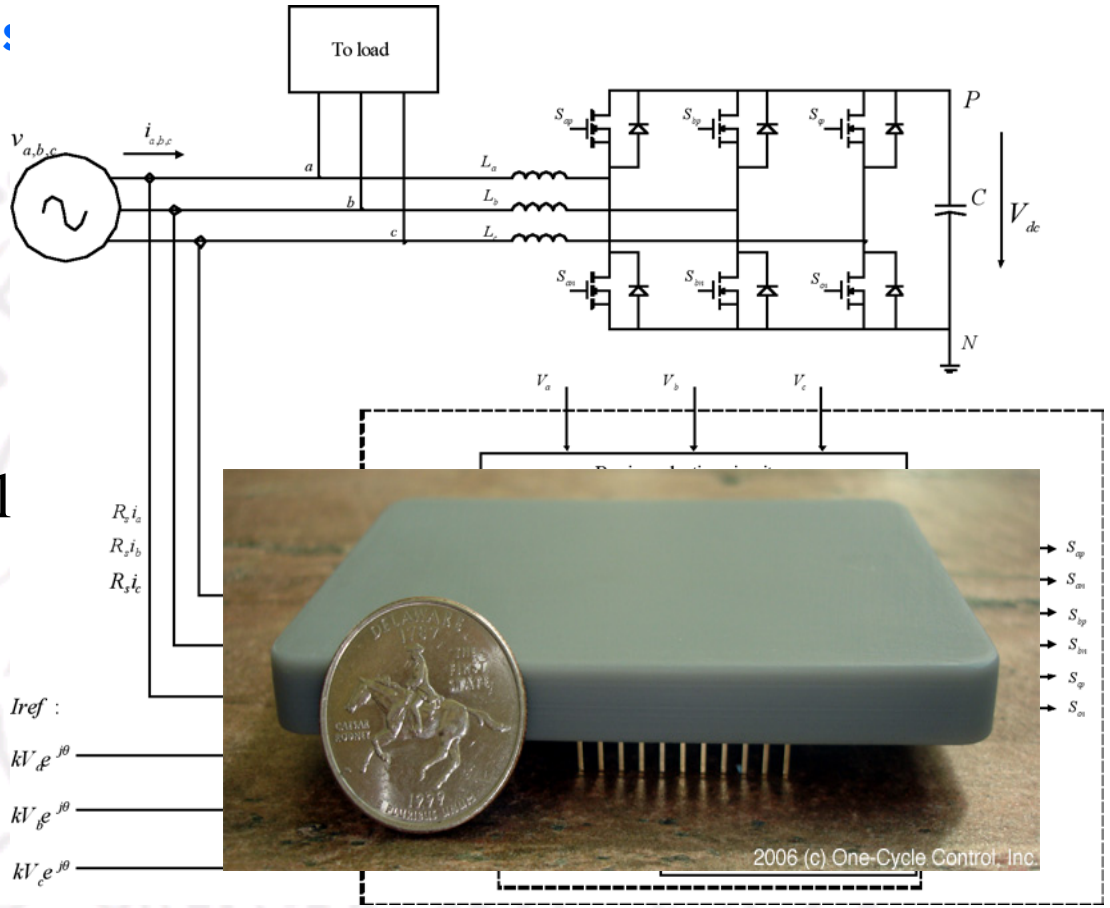
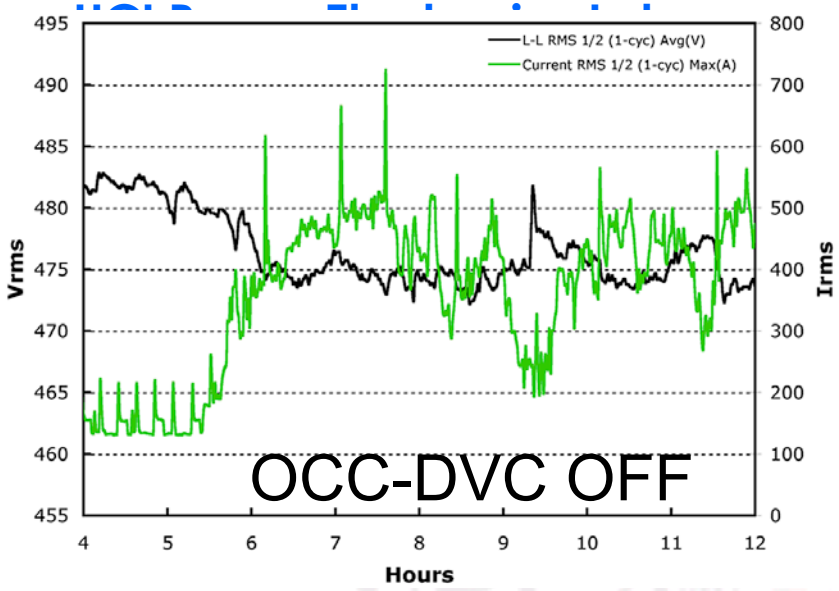
1. AC/DC
2. DC/AC
3. STATCON
4. Bidirectional
5. APF
6. DC/DC

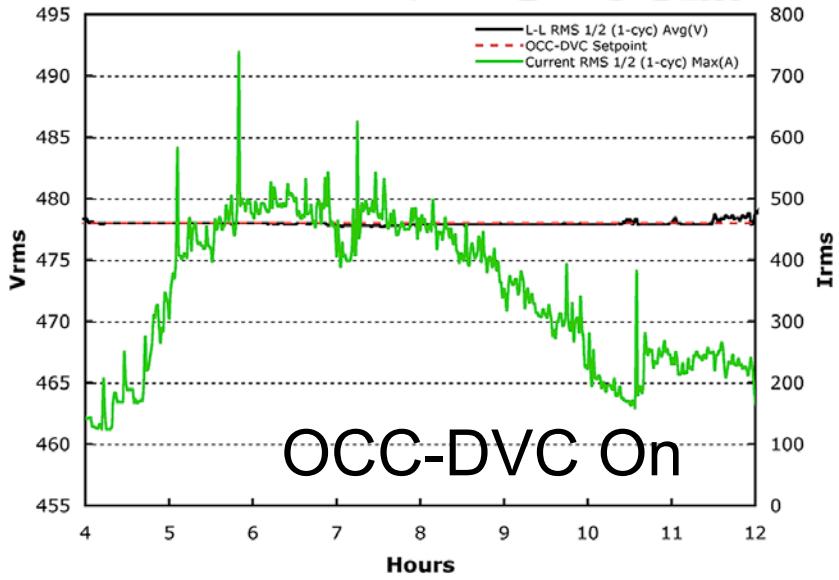


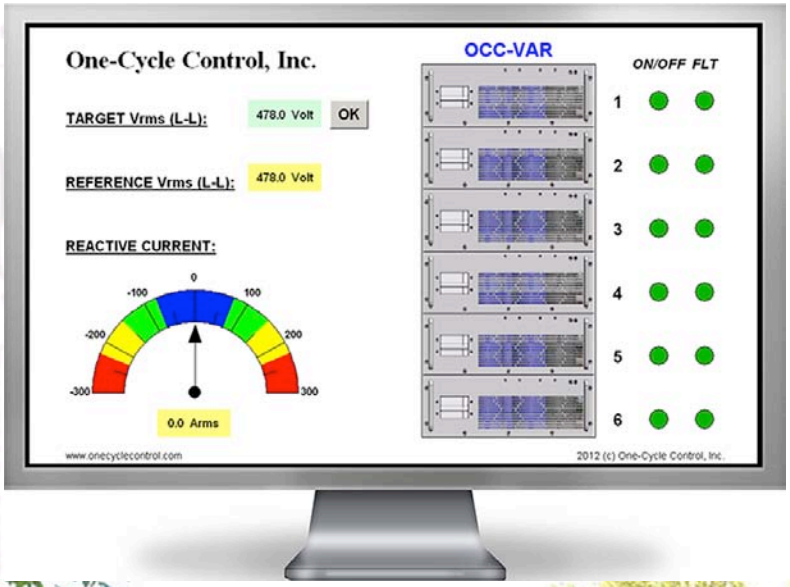
8.5cm x 6cm x 1cm OCC controller

1. Chongming Qiao. Smedley KM. A general three-phase PFC controller for rectifiers with a parallel-connected dual boost topology. IEEE Transactions on Power Electronics, vol.17, no.6, Nov. 2002, pp. 925-34. Publisher: IEEE, USA.
2. Taotao Jin. Lihua Li. Smedley, "universal vector controller for four-quadrant three-phase power converters." IEEE Transactions on Circuits and Systems I: Fundamental Theory and Applications, vol.54, no.2, Feb. 2007, pp. 377-90. Publisher: IEEE, USA.

OCC-DVC for Voltage Control







Courtesy of One-Cycle Control, Inc.

OCC-EnergyS torage

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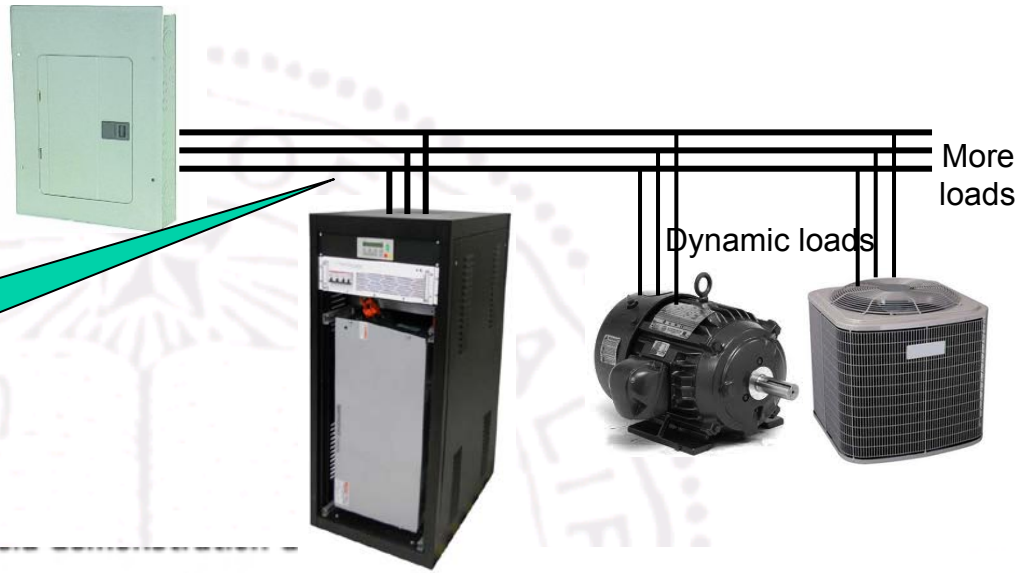
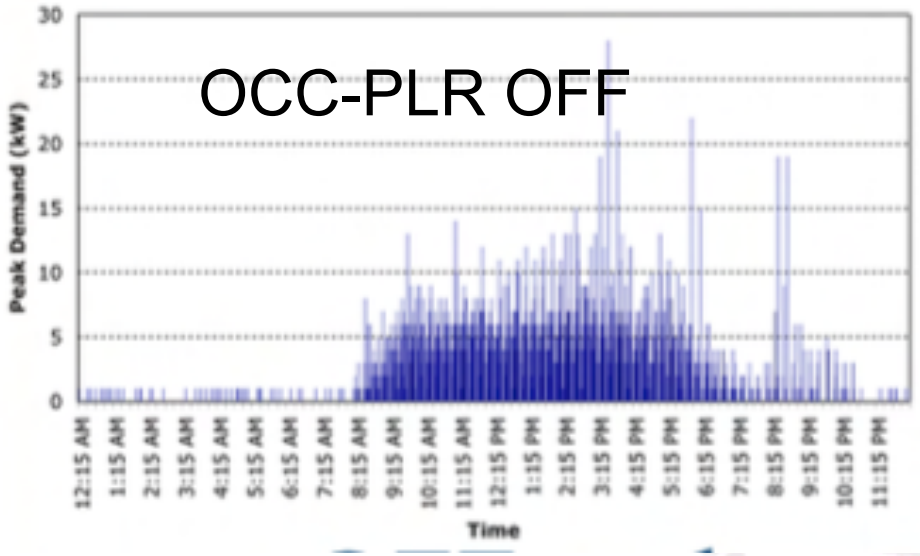
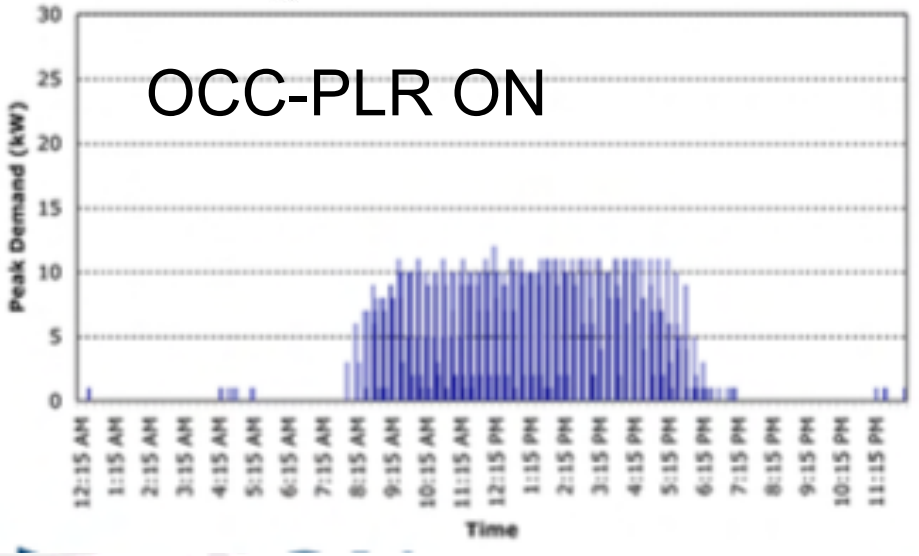
Perform Peak Load regulation

Cut down utility bill







Courtesy of One-Cycle Control, Inc.

OCC-Active Power Filter

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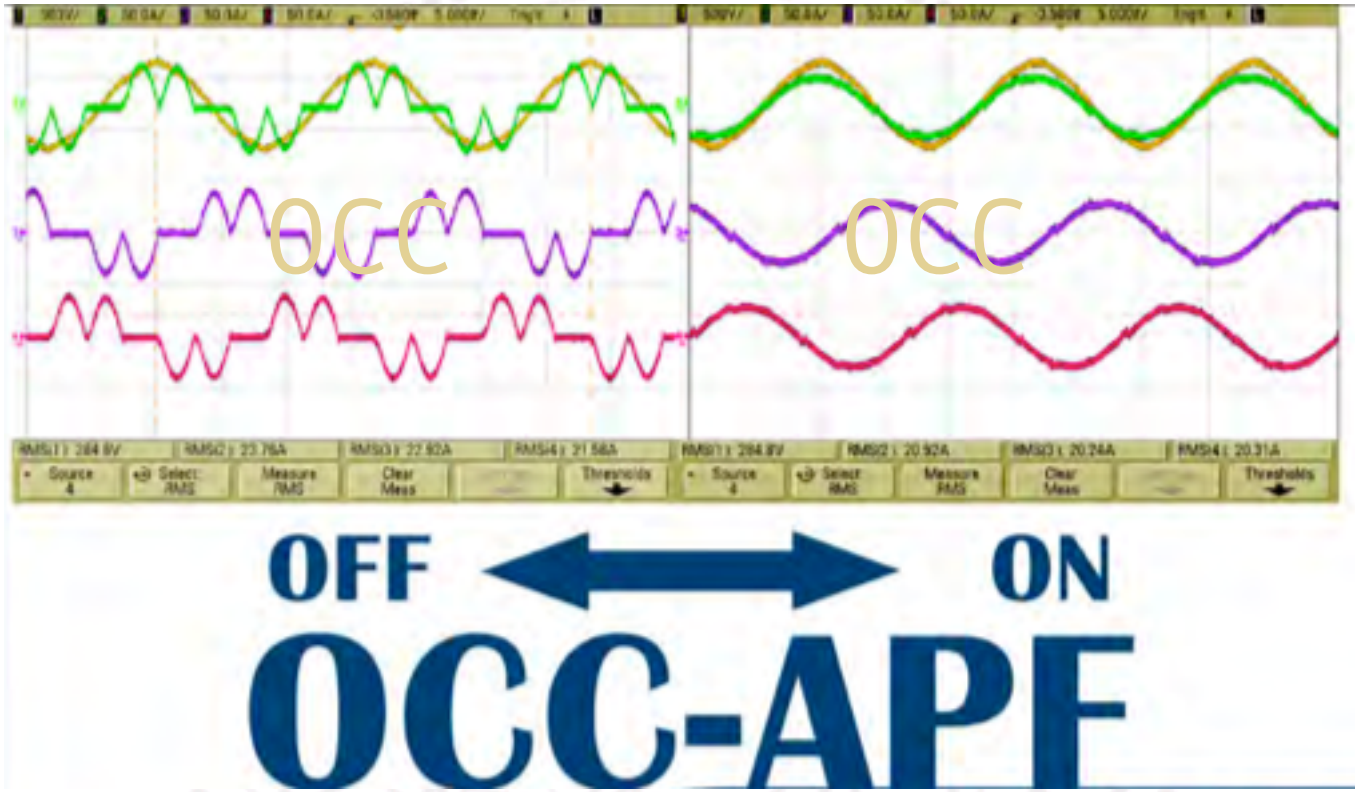


OCC-APF eliminates the current harmonics
reduces apparent power by 20%
Improves power factor from 0.8 to 0.99

Courtesy of One-Cycle Control, Inc.

APF for Net Zero

- Cancels the harmonics (H) and reactive (Q) from the local loads.
- Realize grid connection PF=1

Is Net Zero really Zero?

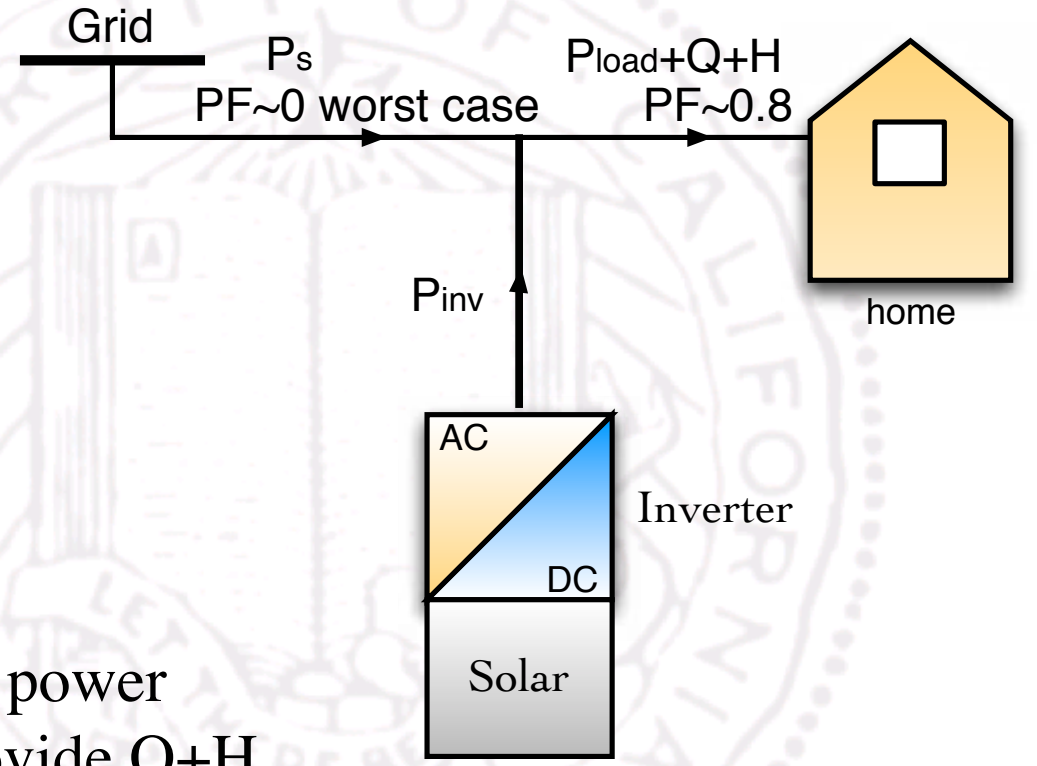
Conventional approach

When

$P_{inv}=P_{load}$

The grid sees

Q+H



=>Grid sells zero power

=>Grid has to provide Q+H

Smart: APF enables Net Zero

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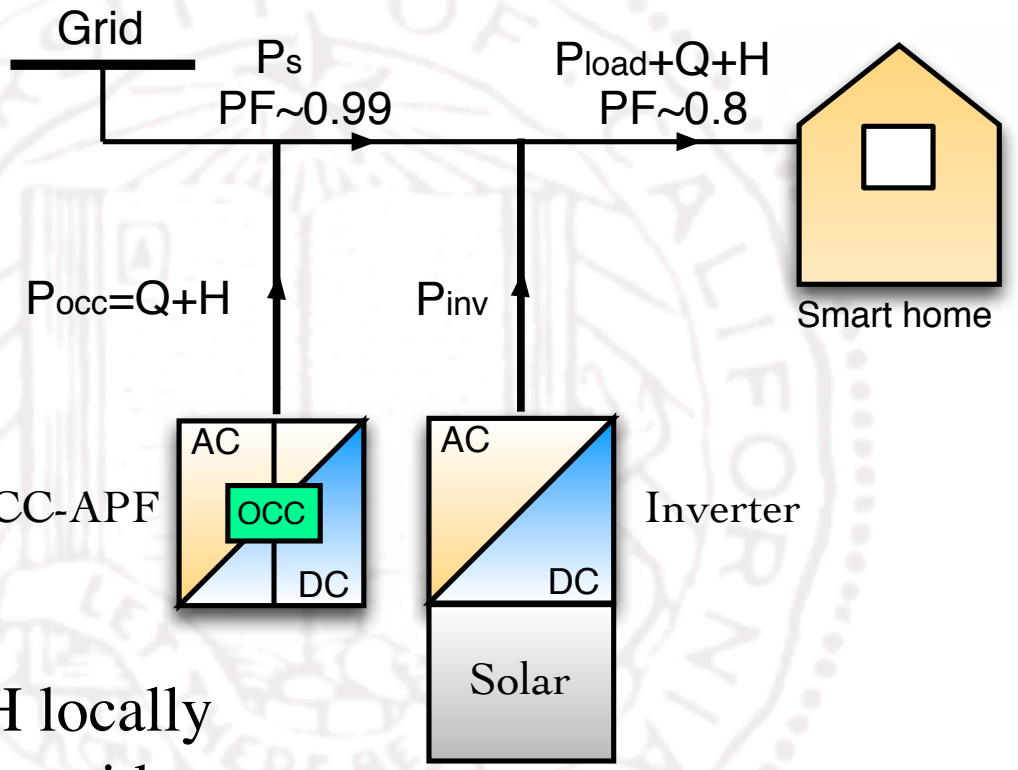
Retrofit APF to inverter

The grid sees

$Q_s=0$

$H_s=0$



APF supplies Q+H locally

=>Clean and stable grid

OCC-APF Implementation

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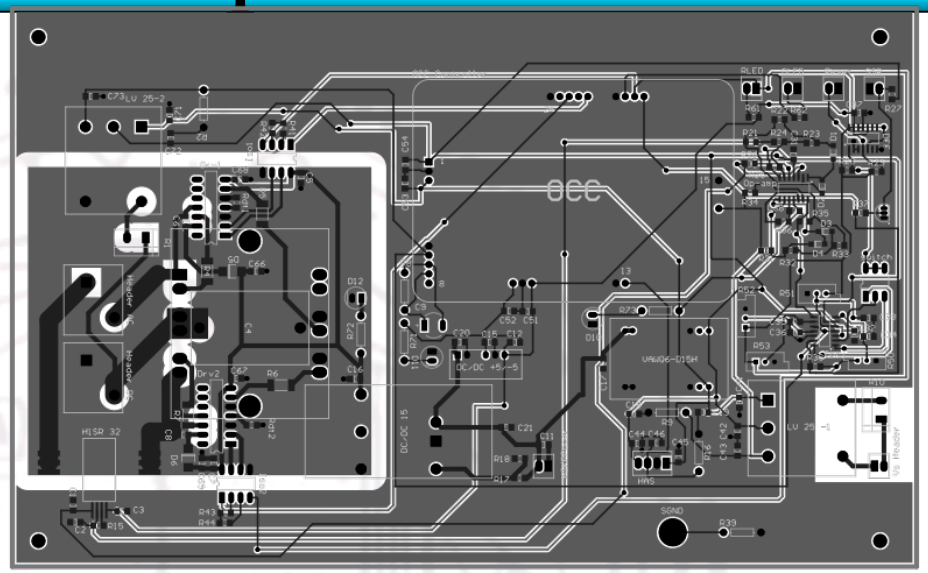
Design parameters
1.5kVA
120V
12.5A

Objective
Grid connection point
power factor=1



OCC-APF prototype, left: front view, right: rear view

Field Test at UCD

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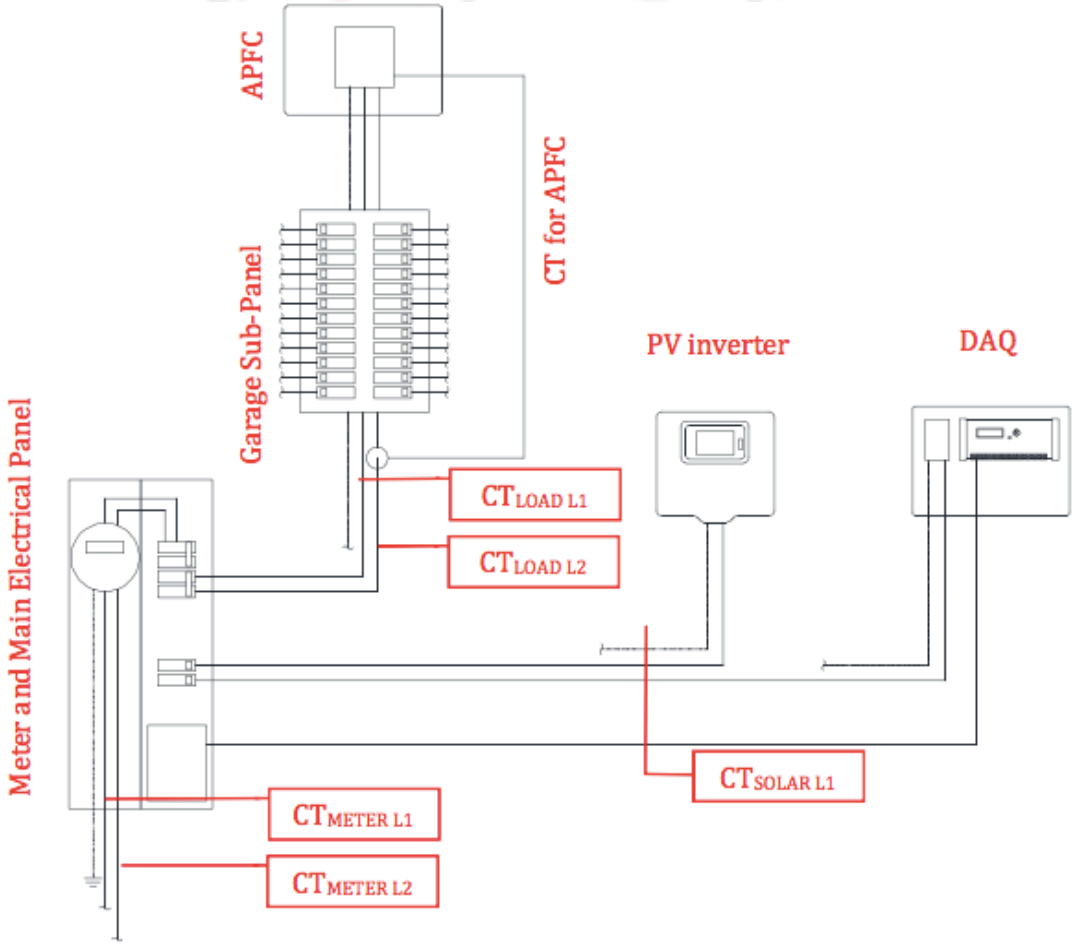

Circuit Diagram for APF test at UCD

Test Data by UCD/UCI Team

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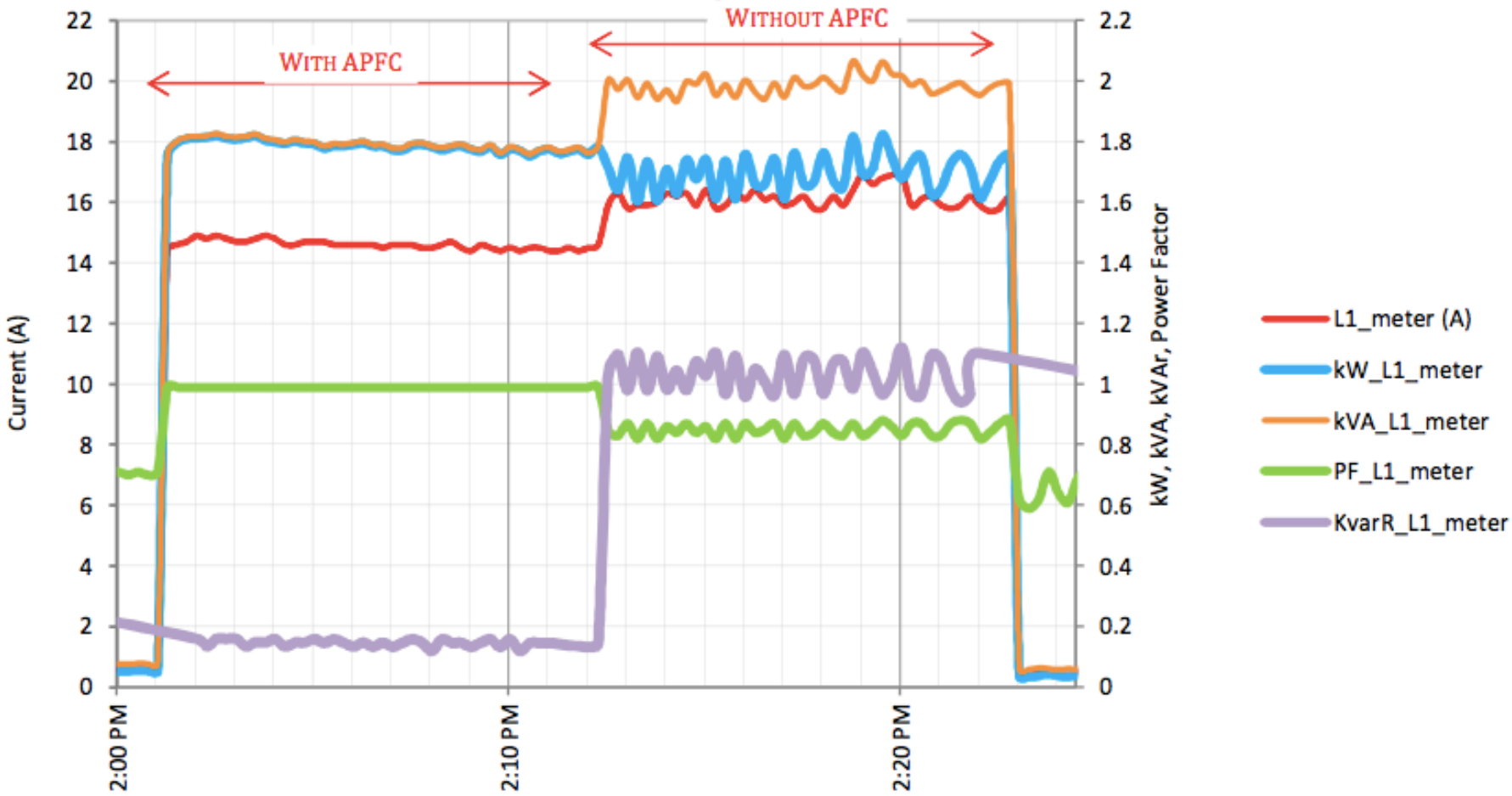

Test loads

- Lights
- Lights & Electronics
- Electronics
- Vehicle Charging
- Kitchen Appliances
- Vacuum & Air Compressor
- Whole House Fan, Water Heater & Vacuum
- Washer & Dryer

Smarter: APF Inverter in One

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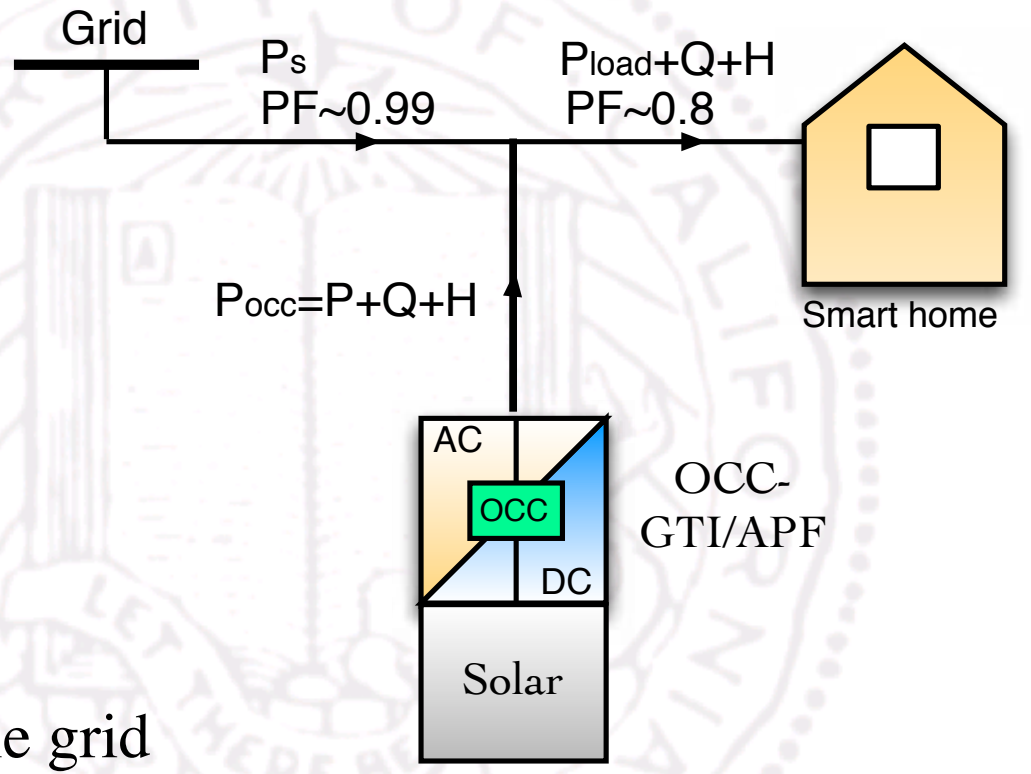
Smart inverter
Grid sees
zero Q+H



OCC APF/Inv
⇒ Supply power
⇒ Cancels Q+H
=>Clean and stable grid

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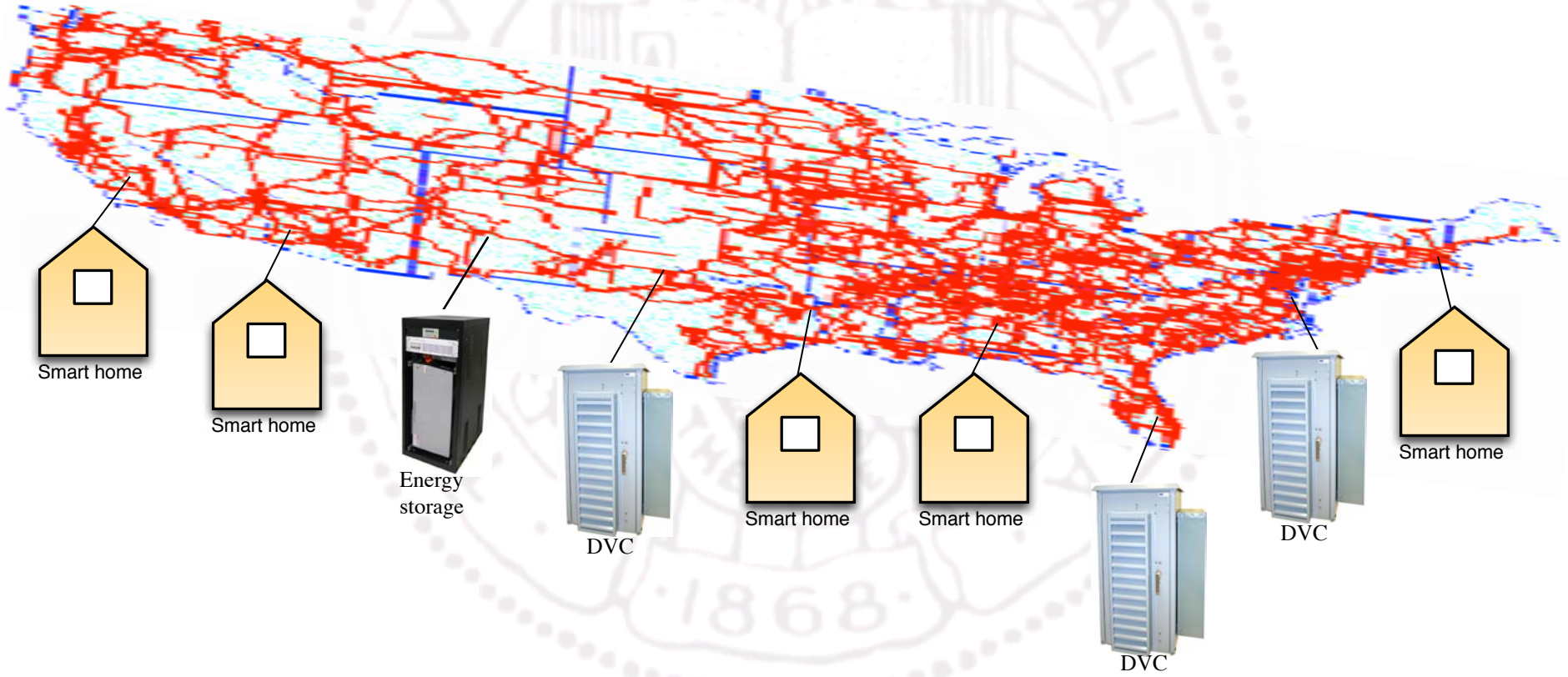
Power electronics enables smart grid

Together we build Energy Super Highway



Thank you !