Renovating the Power System

IEEE Renewable Technology for Green Buildings and Energy Conference

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UC Irvine

Founded in 1965,
23,000 students,
1,300 faculty members
8,100 staff.

3 Nobel Prices Winners

Outline

- Power grid challenge and opportunity
- Smarter grid vision
- Power electronics make grid smarter
  - Congestion control
  - Voltage control
  - Demand control
  - Disaster response
- Power electronics enables energy super highway

The US Power Grid

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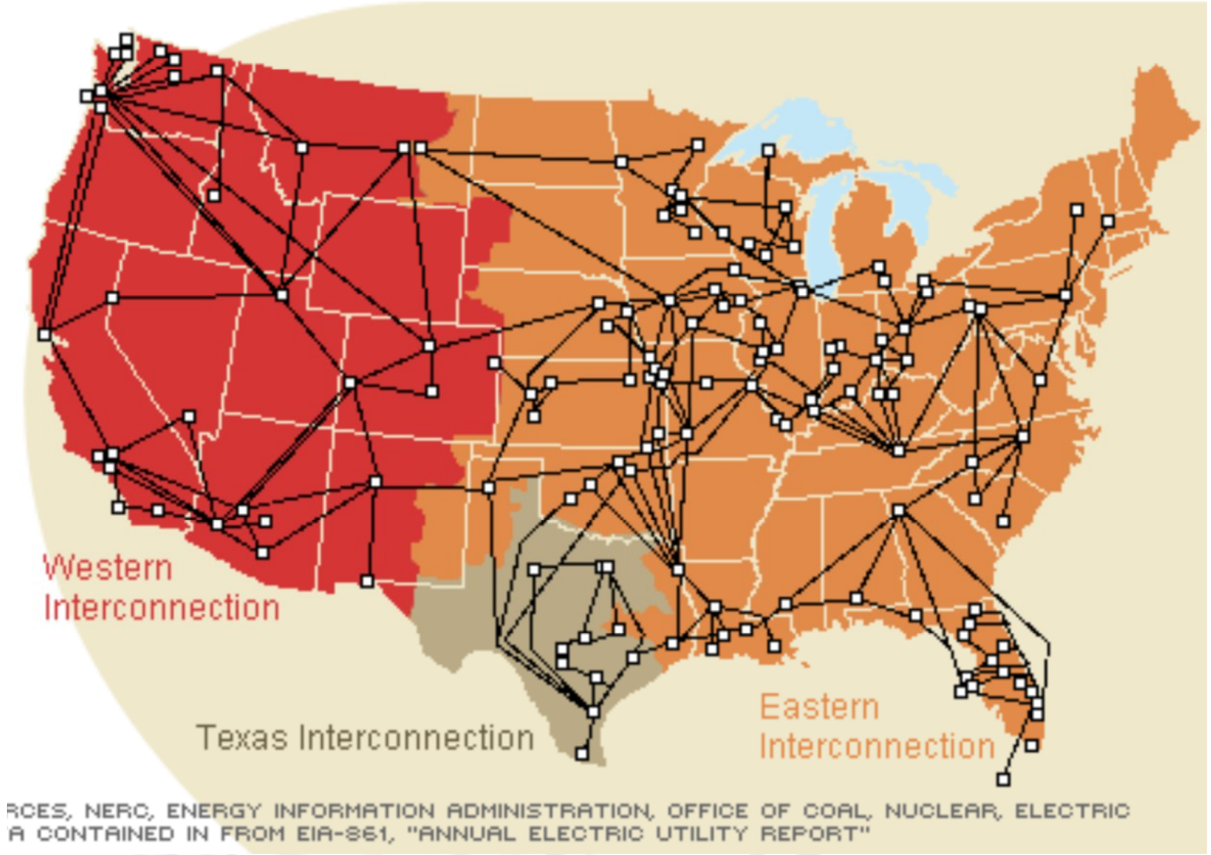
- 680,000 miles of transmission lines
- 5,000,000 miles of distribution lines
-made of L, C, R, transformer, switches, etc.
- with multiple inputs, multiple outputs
- obeys all electric circuit laws



One of the largest machines made by mankind.

Electric Power Grid

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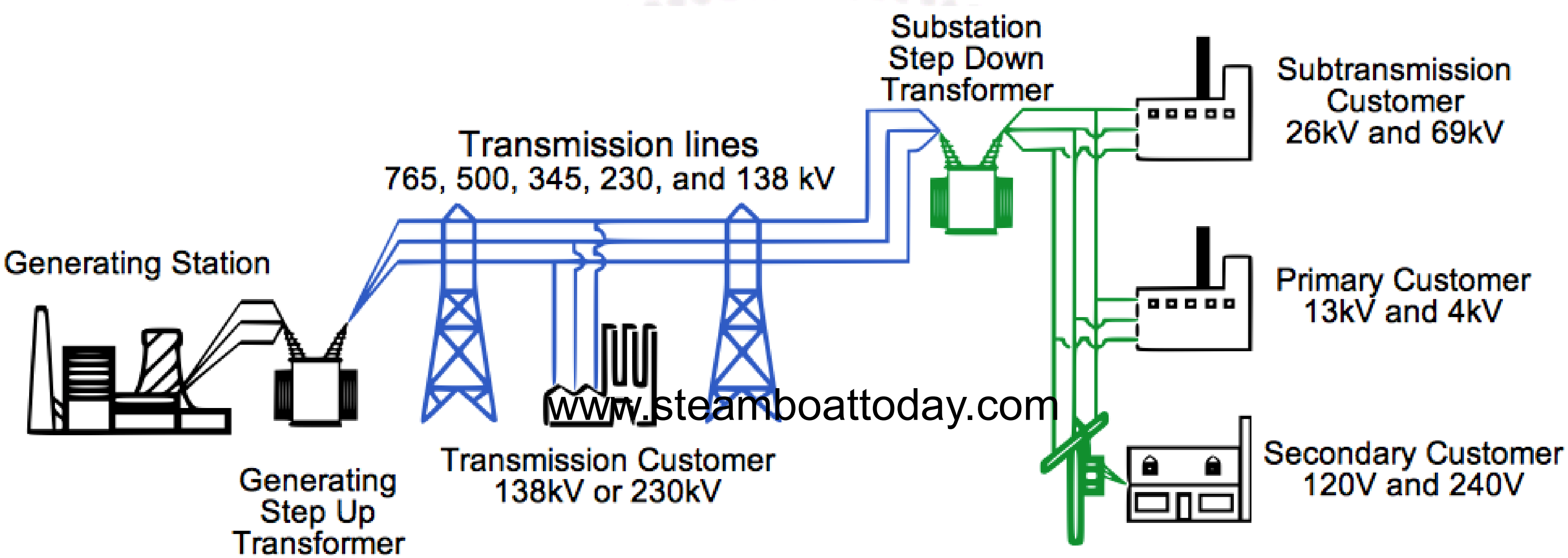

Source: Wikipedia

Photo:steamboattoday.com

Grid Problems

1. Infrastructure updates lag the demand growth
   - Small operation margin
   - Congestion and black out became more frequent
2. 40% of total US energy consumption is for electric power generation
   - The diet of the power grid includes 70% fossil fuels.
   - It is the major contributor for global warming and environmental pollution
3. High DER penetration causes grid instability
   - Systems switching in and out
   - LTC and switched cap banks wear out much more quickly
   - Increase the base load to handle DER fluctuation => defeat the purpose of using DER

Source: Energy information administration

Renewable energy is our future

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Wind==>
Variable frequency power
Variable amplitude
Intermittent

<== Solar
Variable amplitude voltage

Renewable Challenges

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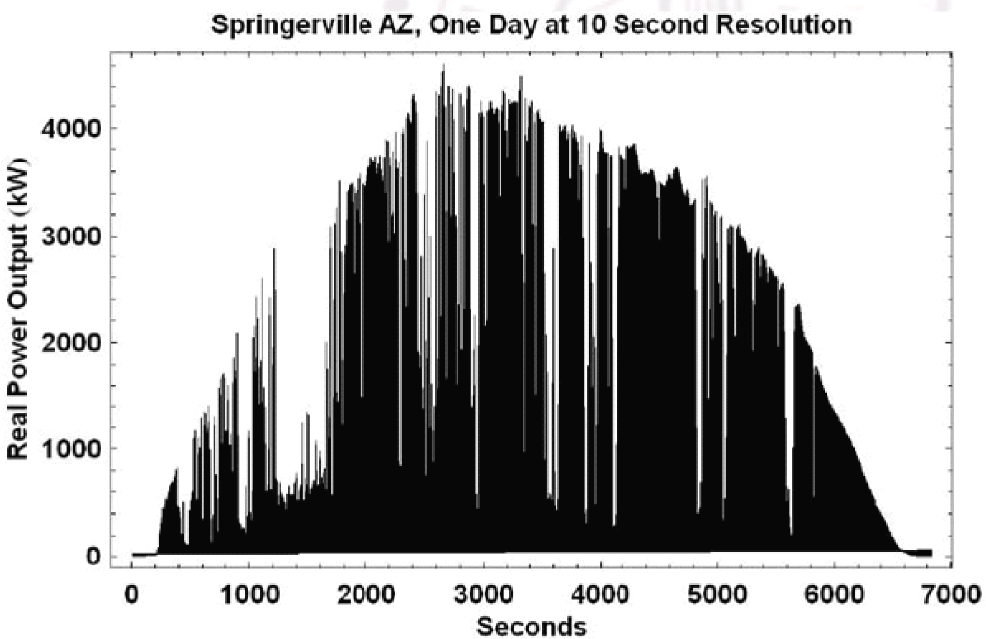
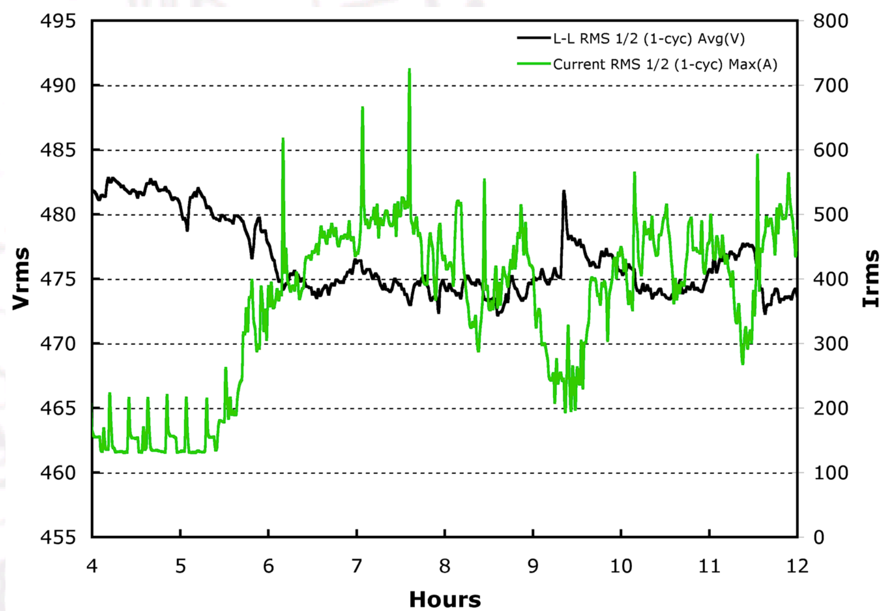
- Unstable DC
- Fluctuation in the day
- Intermittent dynamics
- Distributed

Inverter
Energy Storage
VAR voltage support
Smart grid integration





Source: http://www.megawattsf.com/gridstorage/gridstorage.htm

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

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Grid Challenges & Opportunities

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--Grid Optimization[1,2]

Line loss \$26 billion/year	Efficiency optimization 10% reduction => \$2.6B
Congestion loss \$4.8 Billion/year	Improve capacity 10% congestion reduction =>\$0.48 Billion
Blackout loss \$100 billion/year	Improve reliability 20% reduction =>\$20 Billion
Renewables is limited to 15%	Enable higher renewable penetration 33% by 2020, 50% by 2030 California CPUC
Infrastructure upgrade is limited by economy & environment	Extend the useful life of existing infrastructure Keep the add-on cost down

1. Power System Optimization Smart Grid, Demand Dispatch and Microgrids, Joe Miller - Smart Grid Implementation Strategy Team Lead September 27, 2011

2. 10 Smart Grid Benefits, DOE Modern Grid Strategy, August 2007

3. LANL Solar Smart Grid, 1663 Science and Technology Magazine

Smarter Grid--A Vision

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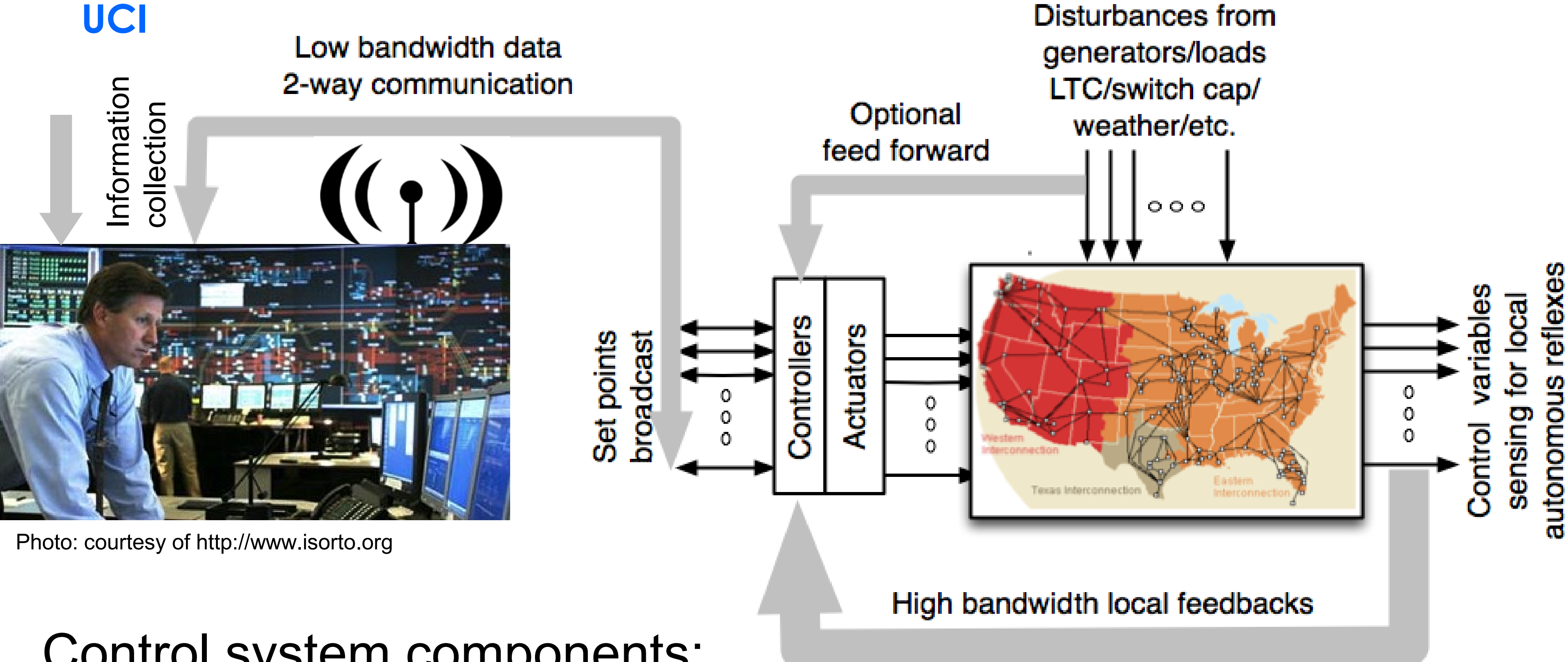

Photo: courtesy of http://www.isorto.org

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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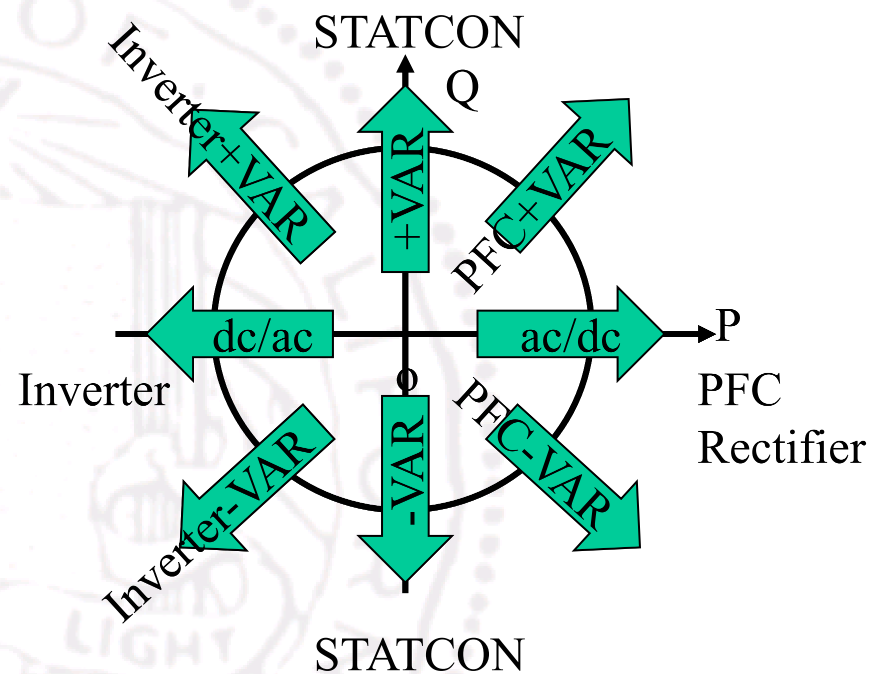
--enabling smarter grid

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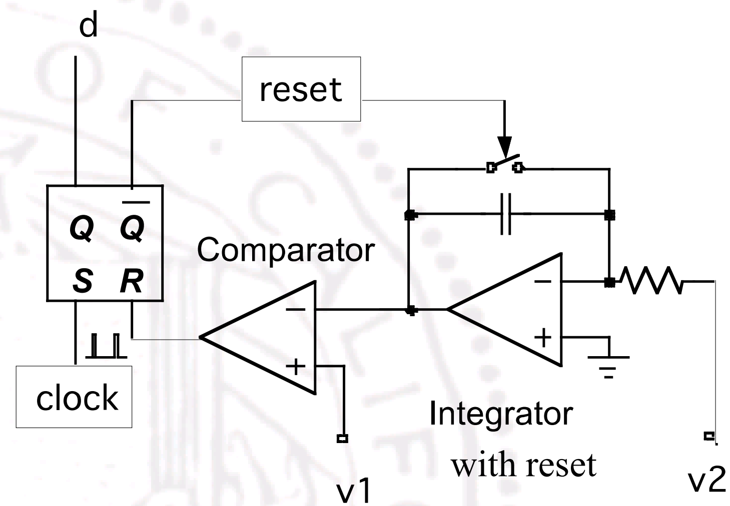
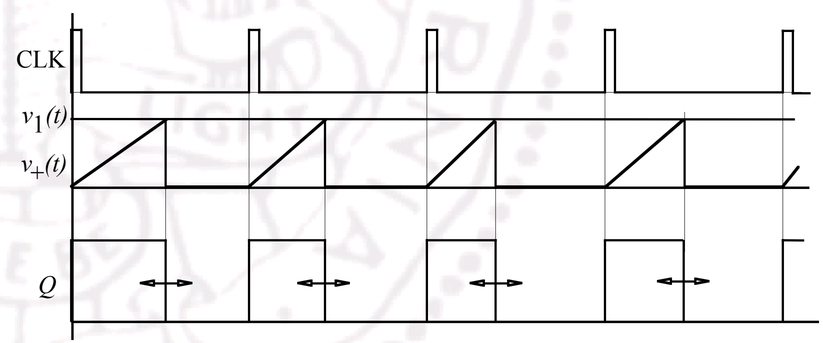
$$1/T_s \int_0^t V_2 dt = V_1 \qquad t = dT_s$$

$$V_2 d = V_1$$

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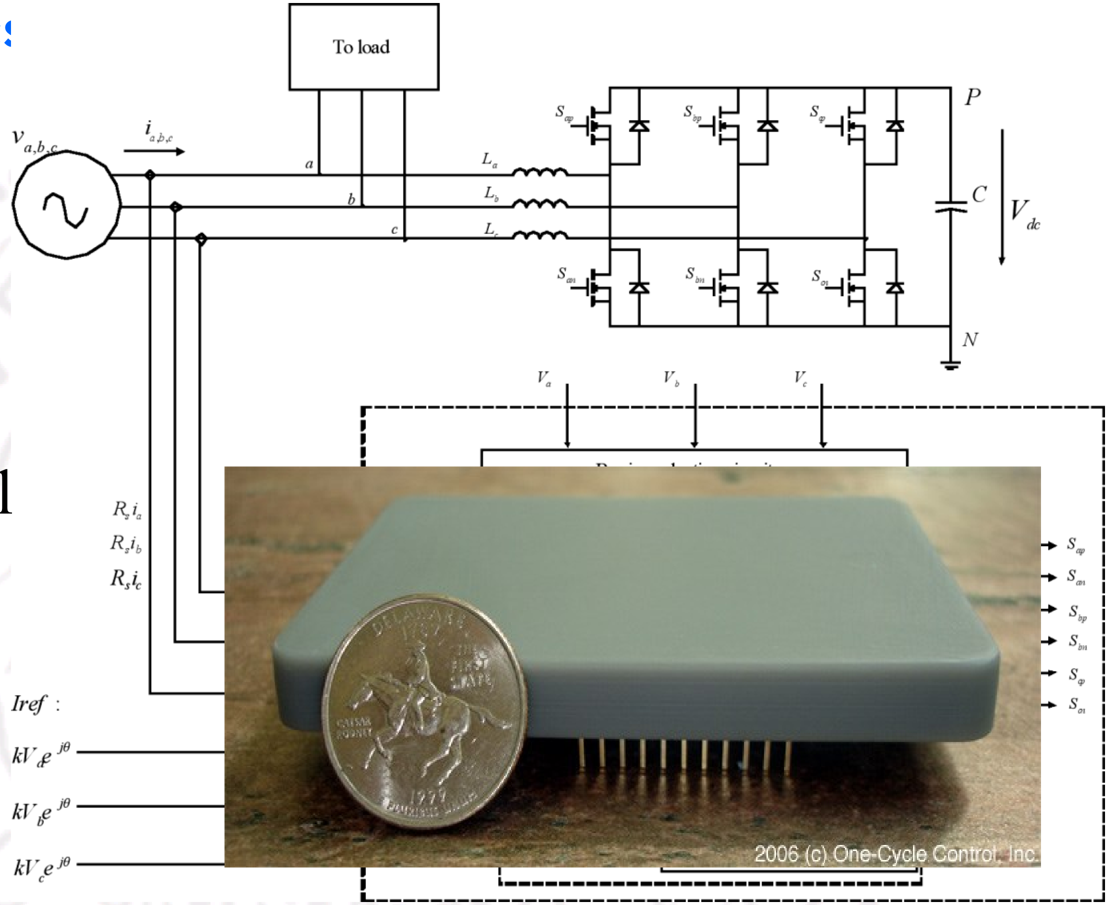
1. AC/DC
2. DC/AC
3. STATCON
4. Bidirectional
5. APF



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.

4-Quadrant Power Converter

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--grid control actuator

Smart grid building block

60kVA, 65lb

APF--reduce loss, congestion

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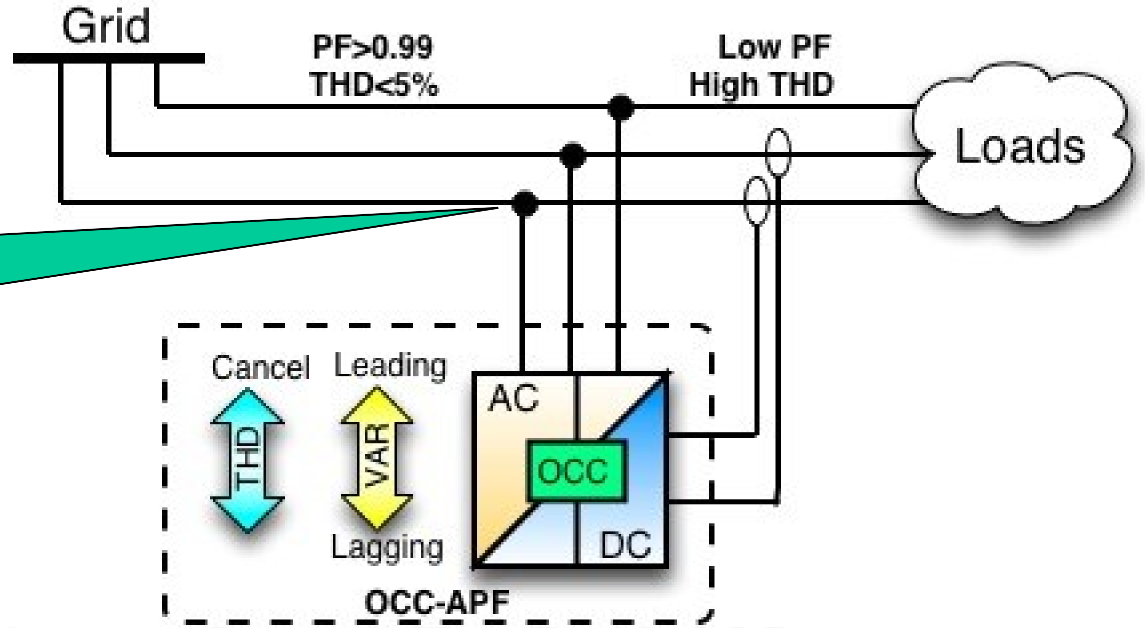
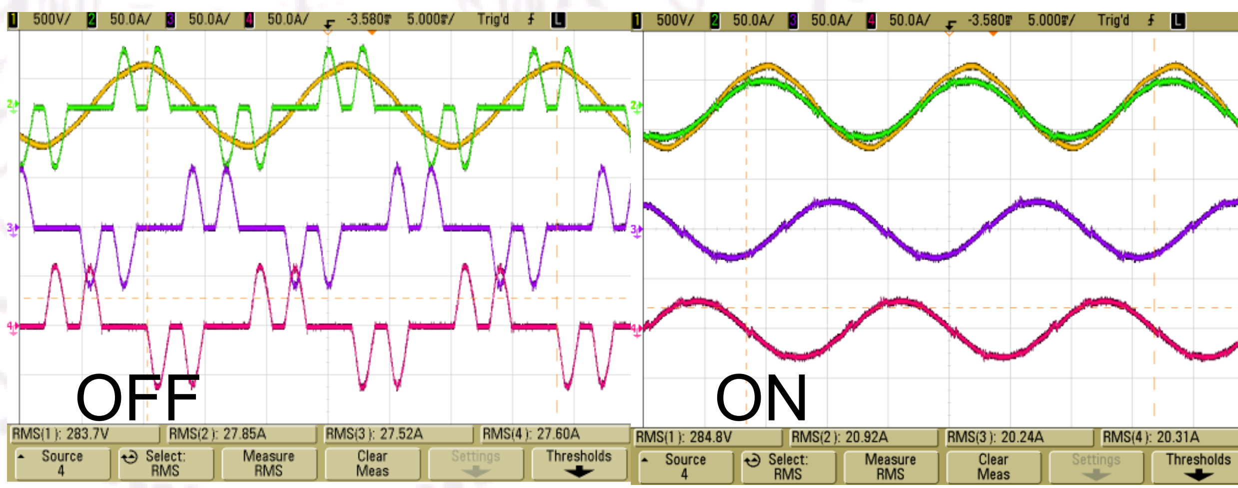


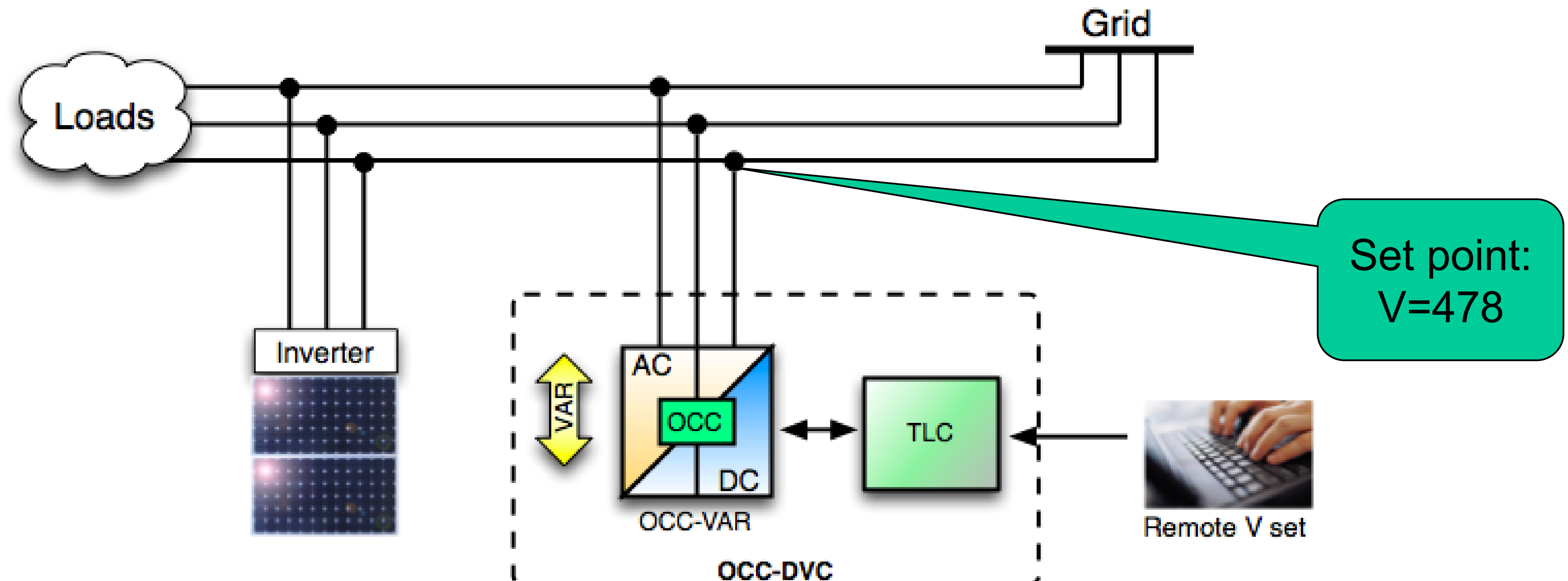
Set point:
PF=1
THD<5%

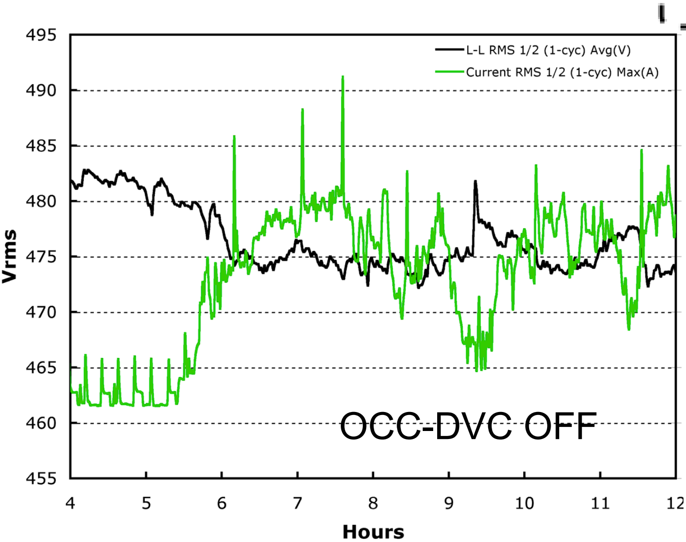
- Reduces apparent power by 20%
- Improves PF from 0.8 to 0.99

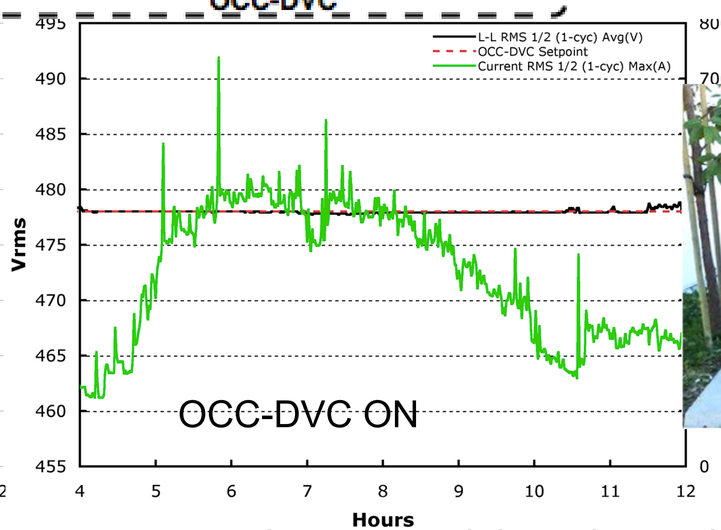


Courtesy of One-Cycle Control, Inc.

DVC--stabilize voltage







Courtesy of One-Cycle Control, Inc.

OCC-DVC (Voltage Schedule)

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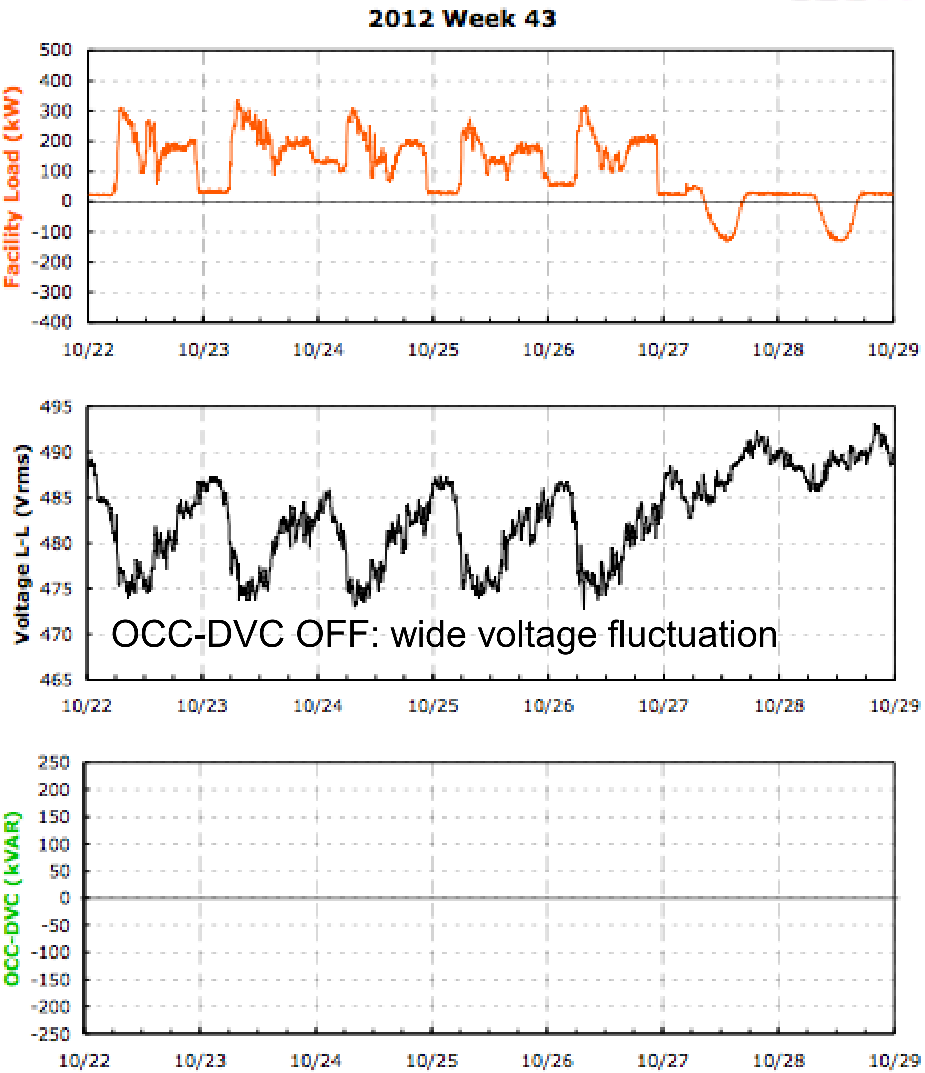
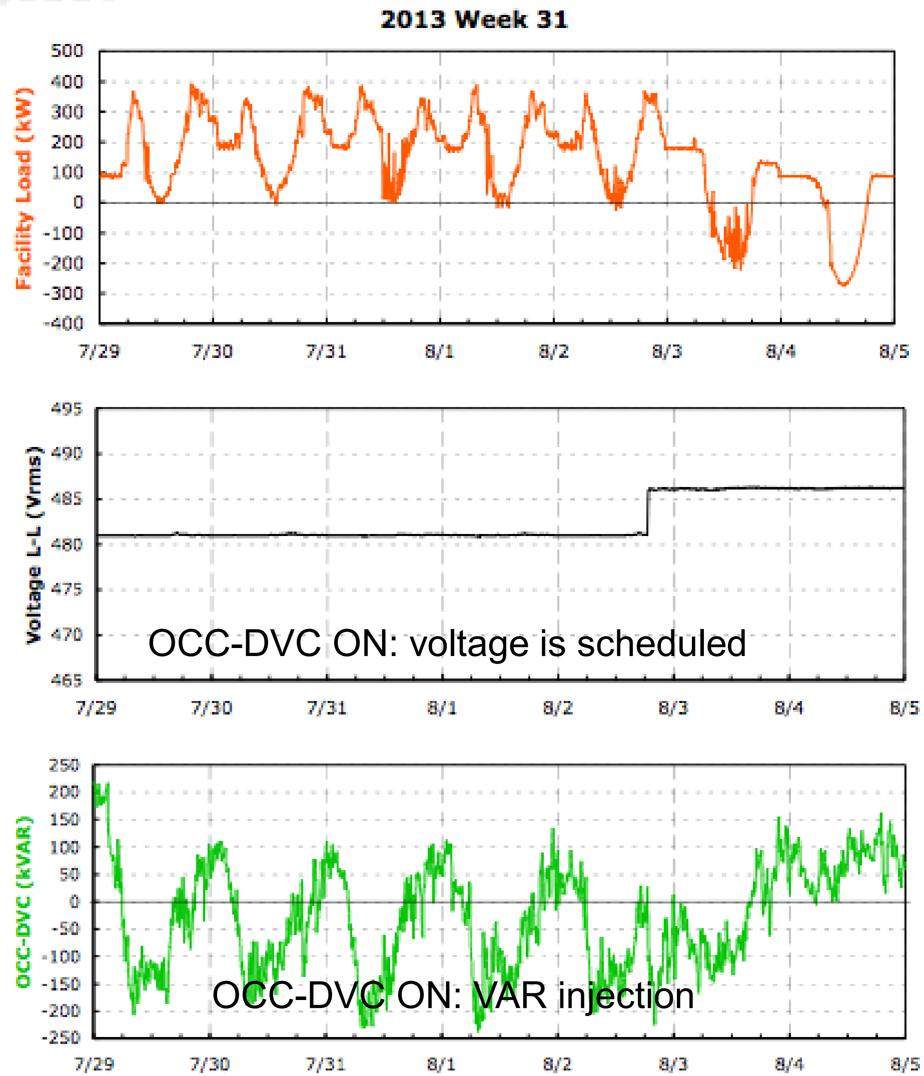
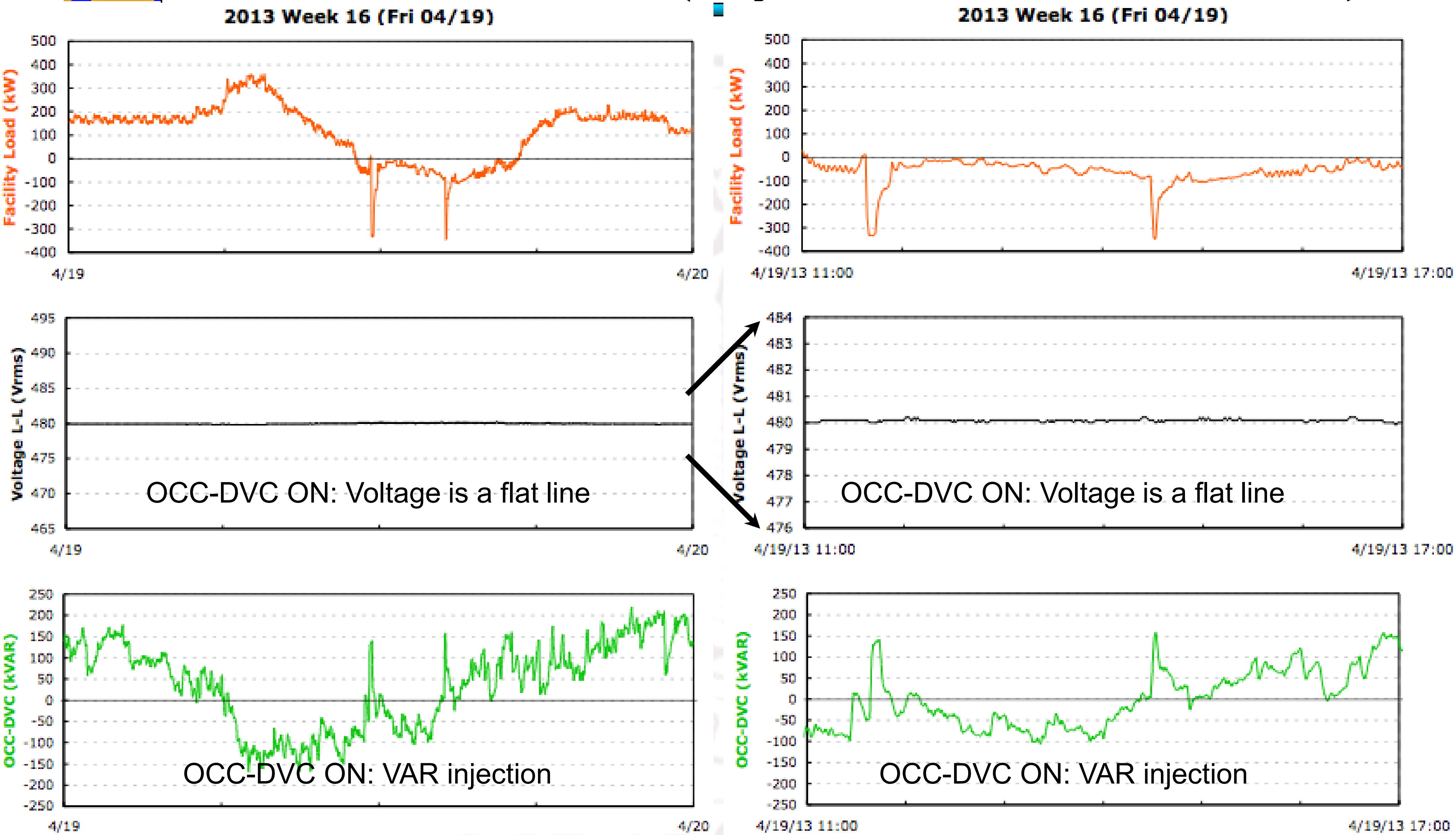
OCC-DVC = OFF



OCC-DVC = ON



OCC-DVC (Dynamic Load&PV)



Full Day - 2 Load Drops **Zoom In - 6 hours**

October 18, 2013, 9:03AM

500kV line fault
Voltage sag was detected in every substation
Except the one with OCC-DVC ON

PLR--demand control

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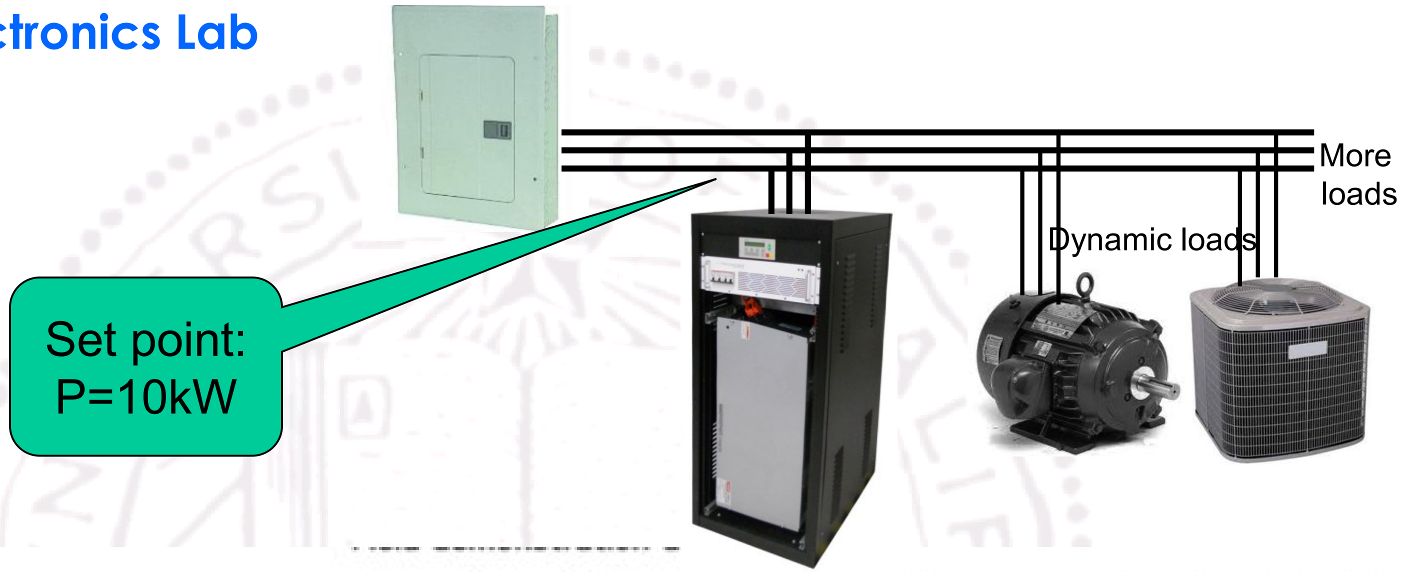

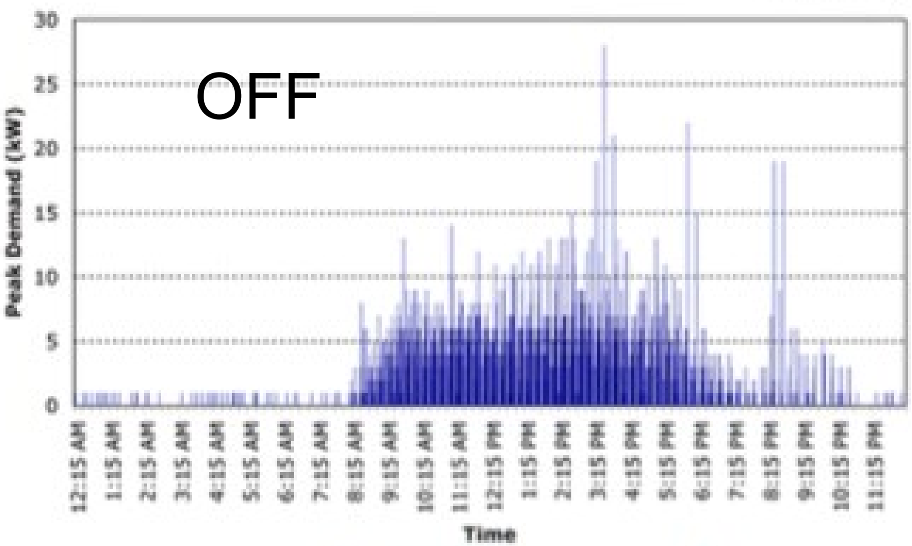

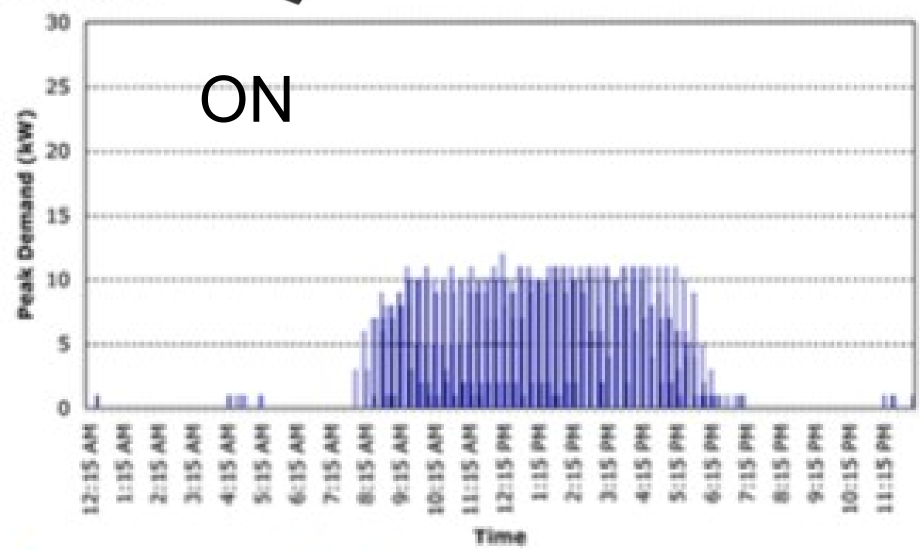

Courtesy of One-Cycle Control, Inc.

Wide-area Voltage Profile Control

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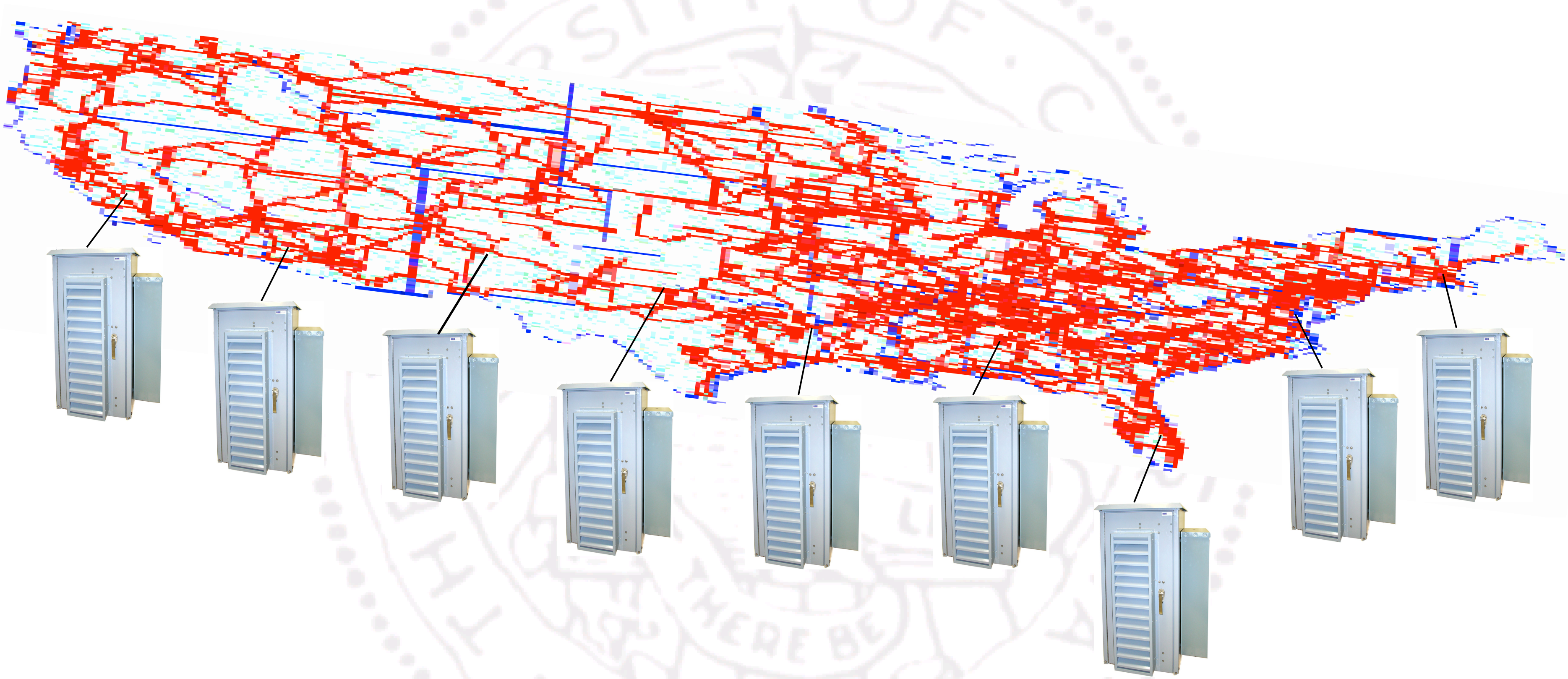

Pave Power Electronics Super Highway

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- Clinton Administration built silicon-based information super highway
  - Revolutionized IT industry
- It is time to build a silicon-based power electronics super highway
  - Revolutionize power grid=>smarter, more efficient, less congestion, more reliable, less CO_2
  - All renewable generation, all storage, all grid control need power electronics
  - Silicon has proven advantages in speed, controllability, and power handling capability
  - Universal power converter with ultrafast control speed is technically proven and commercially available

Courtesy of One-Cycle Control, Inc.


Thank you !