UCI Power Electronics Lab

Secure Power in High Renewable Penetration Environment

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2. One-Cycle Control, Inc. Irvine

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US Power Generation

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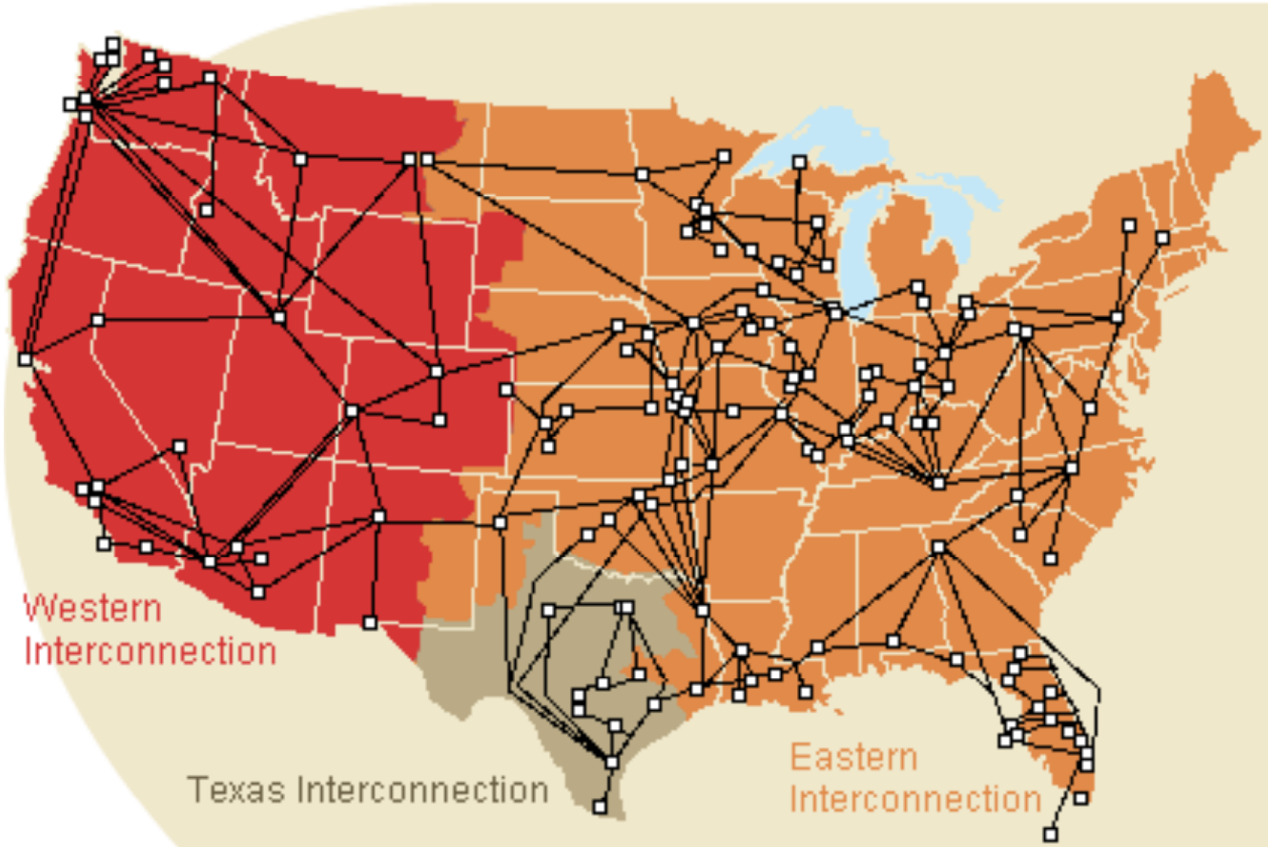
2020:

- 4,009,000 GWh
- 60% Fossil
- 20% Nuclear
- 20% Renewables (including hydroelectric)



SOURCES: DISTRIBUTED ENERGY RESOURCES, NERC, ENERGY INFORMATION ADMINISTRATION, OFFICE OF COAL, NUCLEAR, ELECTRIC AND ALTERNATE FUELS. BASED ON DATA CONTAINED IN FROM EIA-861, "ANNUAL ELECTRIC UTILITY REPORT"

US Renewable Generation

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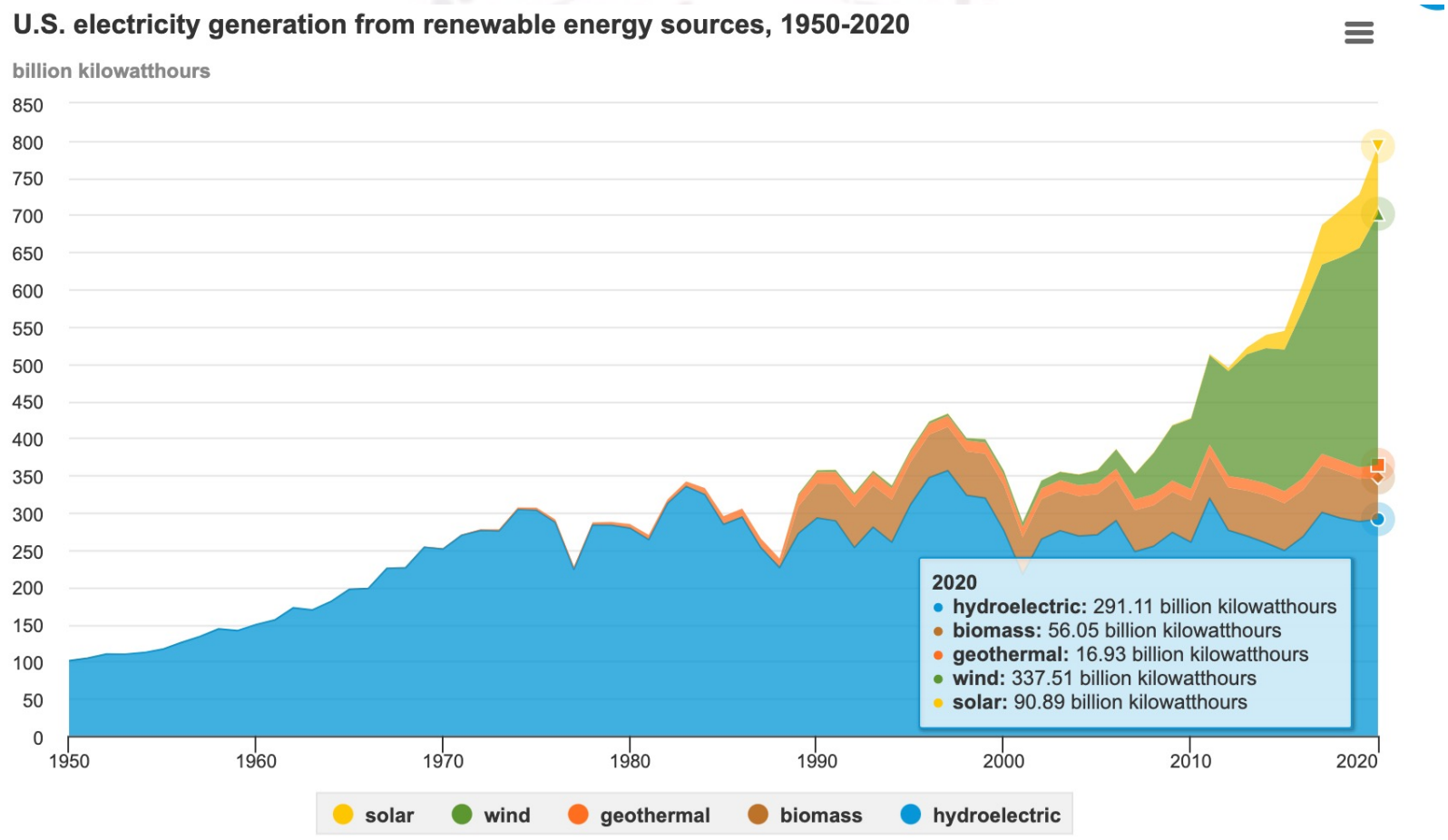

Note: Electricity generation from utility-scale facilities. Hydroelectric is conventional hydropower.
Source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 7.2a, January 2021 and *Electric Power Monthly*, February 2021, preliminary data for 2020

Renewable Challenges

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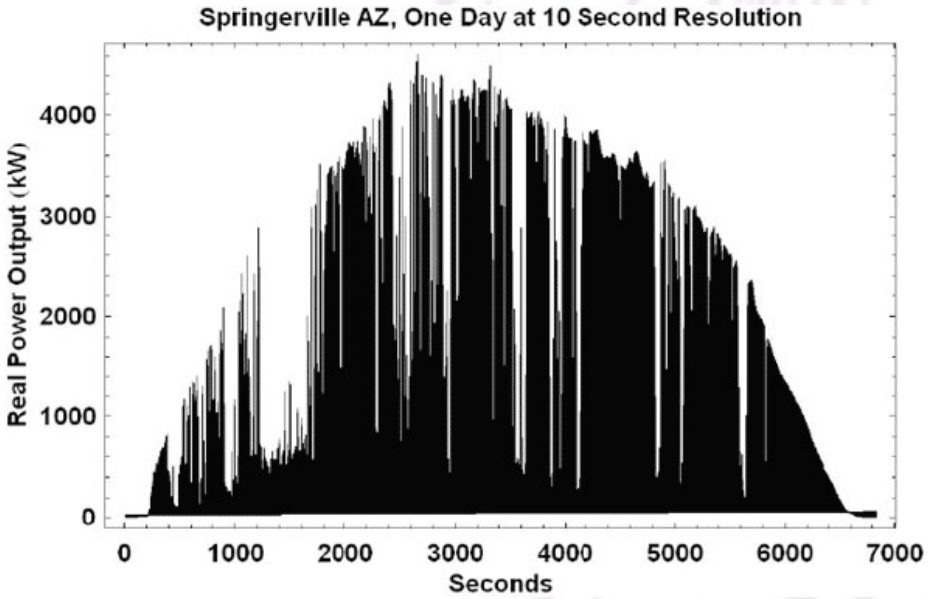
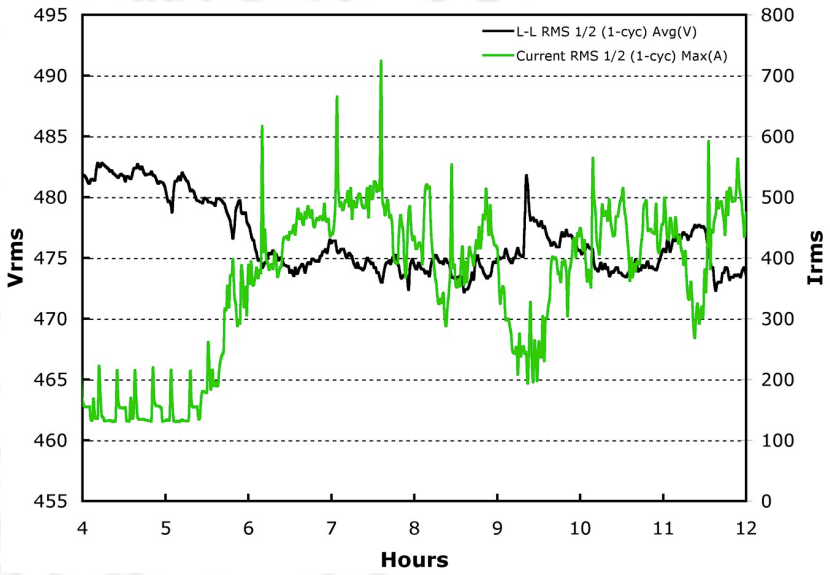
- Intermittency
- Fast Transient

- Voltage instability
- Voltage regulation equipment wear out prematurely
- Black out, brown out





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

Source: One-Cycle Control, Inc.

VAR Stabilizes Power Grid

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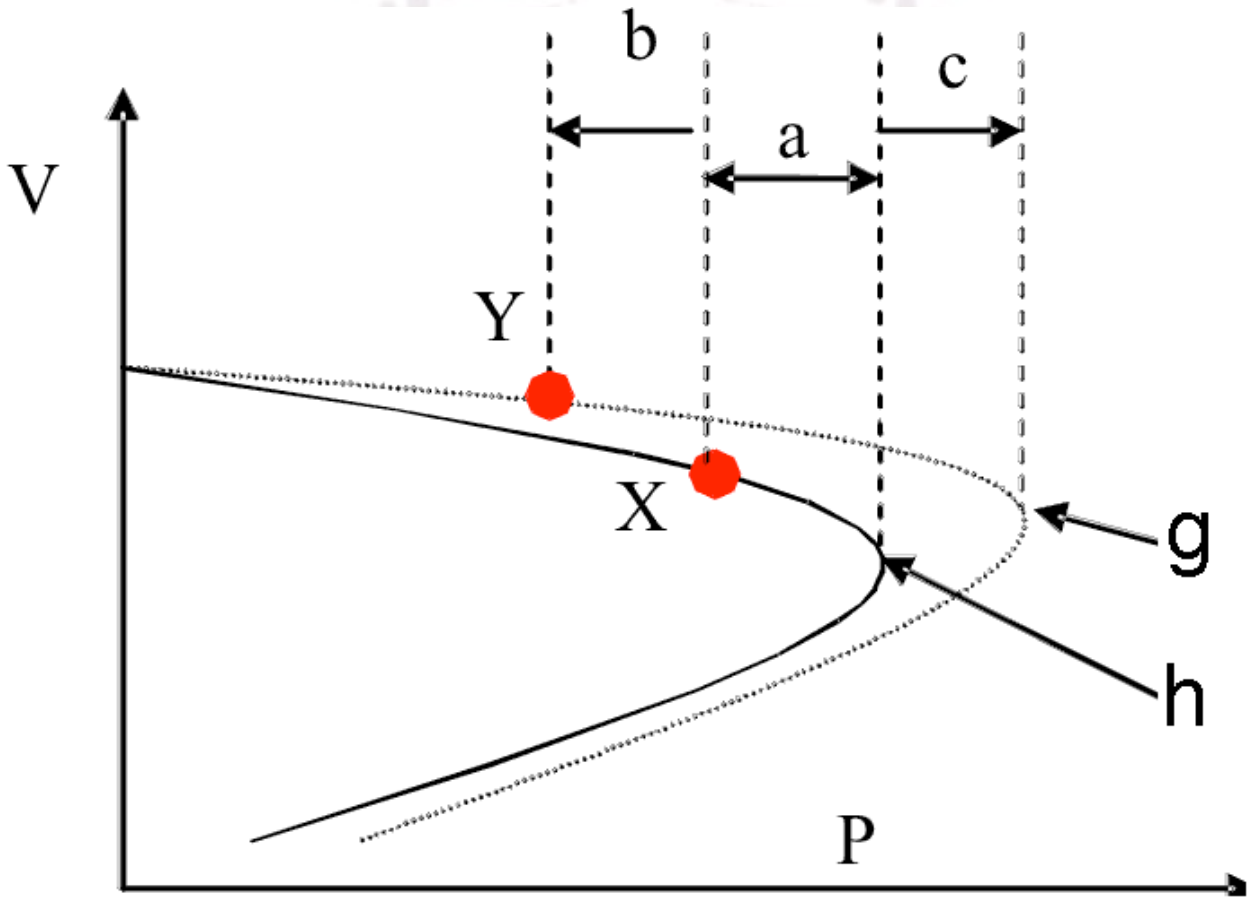

By extending the margin before voltage collapsing

Power Electronics

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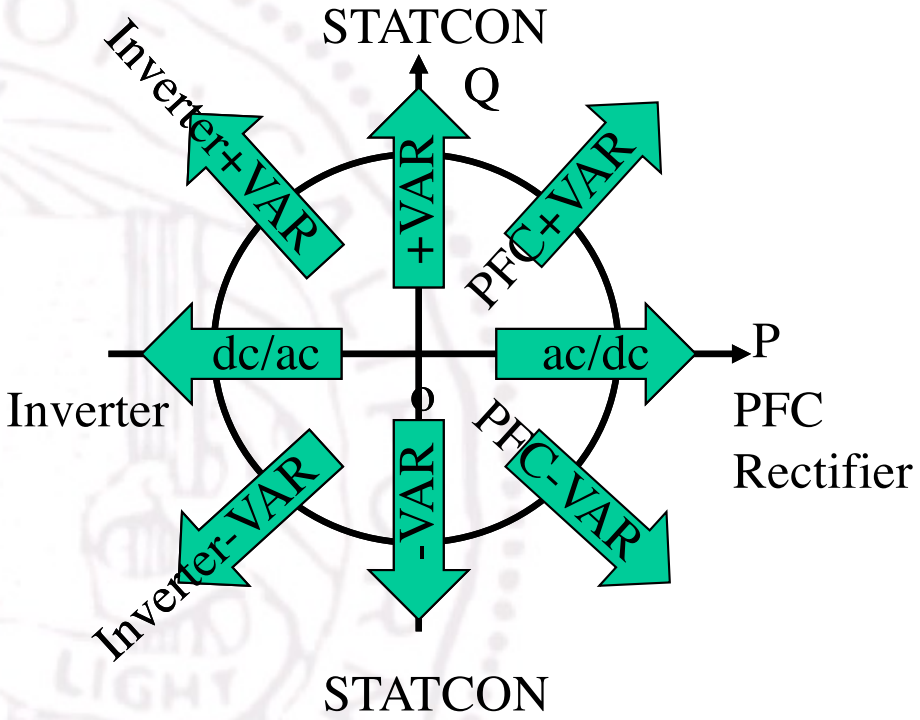
--enabling high penetration

- Silicon has revolutionized IT. It is time to modernize 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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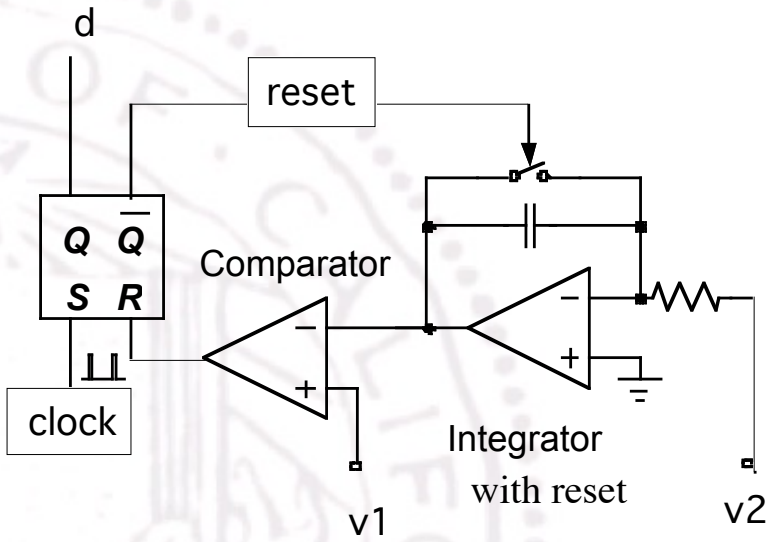
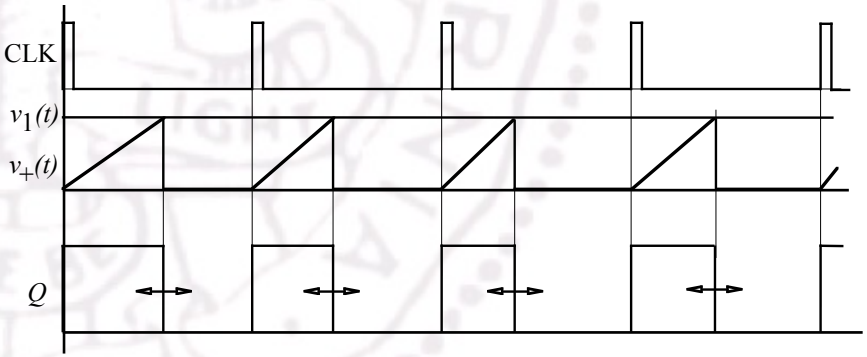
$$1/T_s \int_0^t V_2 dt = V_1$$
$$t = dT_s$$

$$V_2 d = V_1$$

- 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

OCC-DVC

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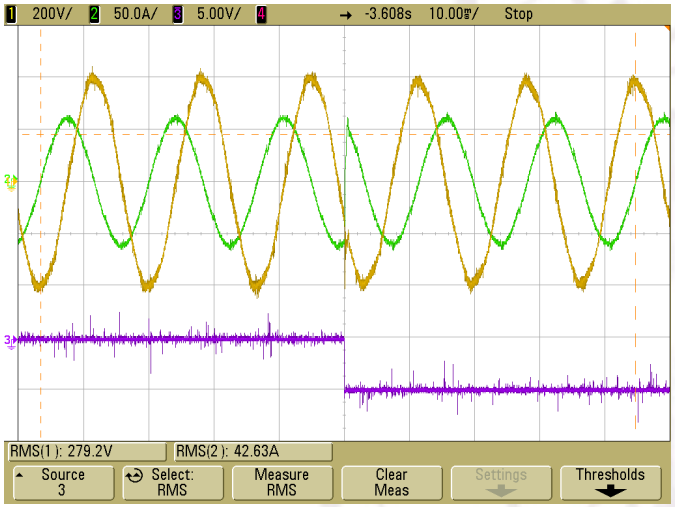
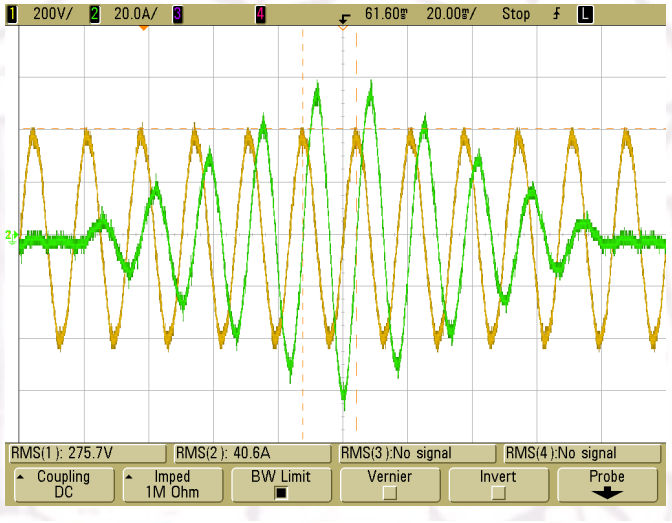
--Smart Grid Building Blocks

+Q to -Q



Q ramps up/down



High efficiency
Fast response
Small footprint

±60kVAR

±360kVAR

Source: One-Cycle Control, Inc.

OCC-DVC--stabilize voltage

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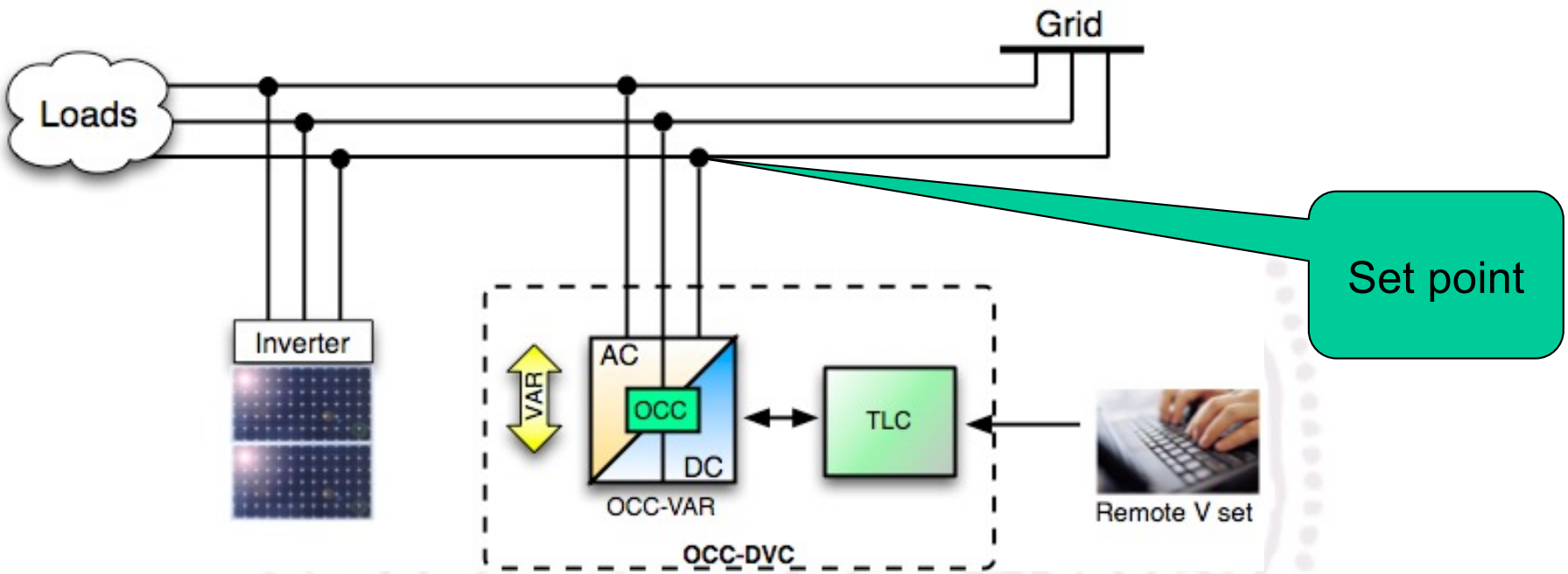

Source: of One-Cycle Control, Inc.

SDGE Installation

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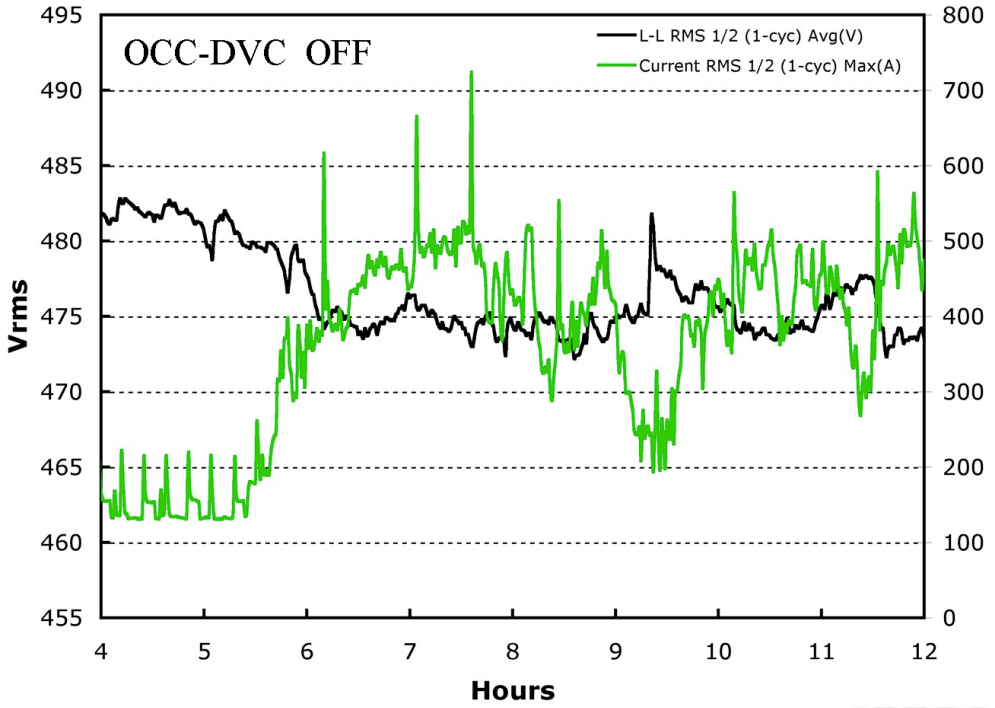
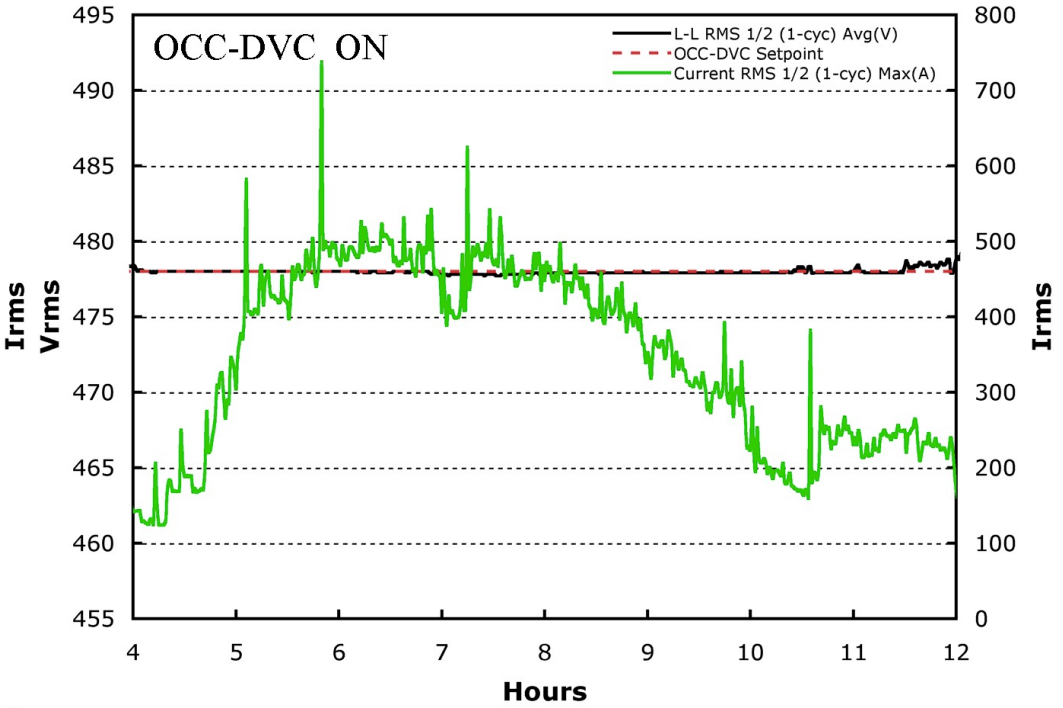
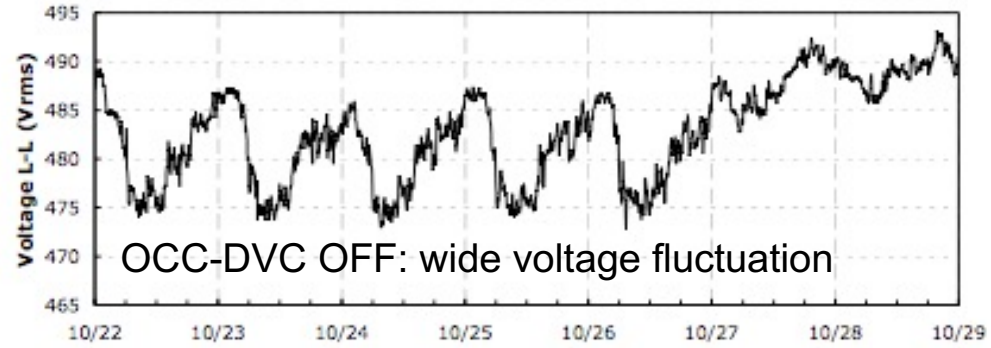
OCC-DVC —
Quench the transient
Regulate the voltage to a flat line



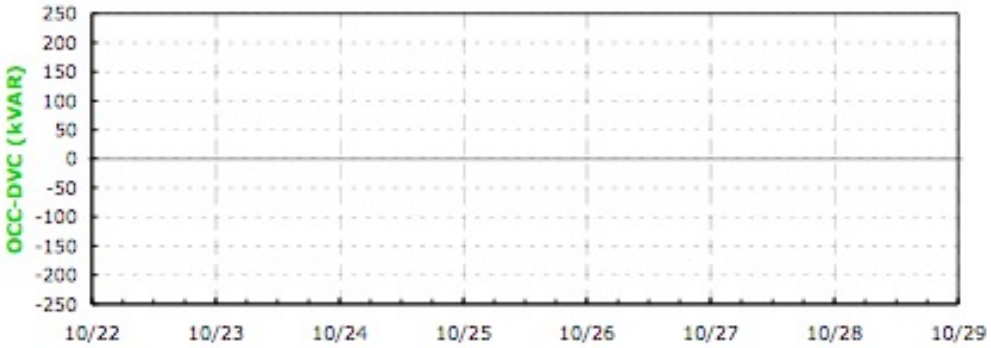


OCC-DVC (Voltage Schedule)

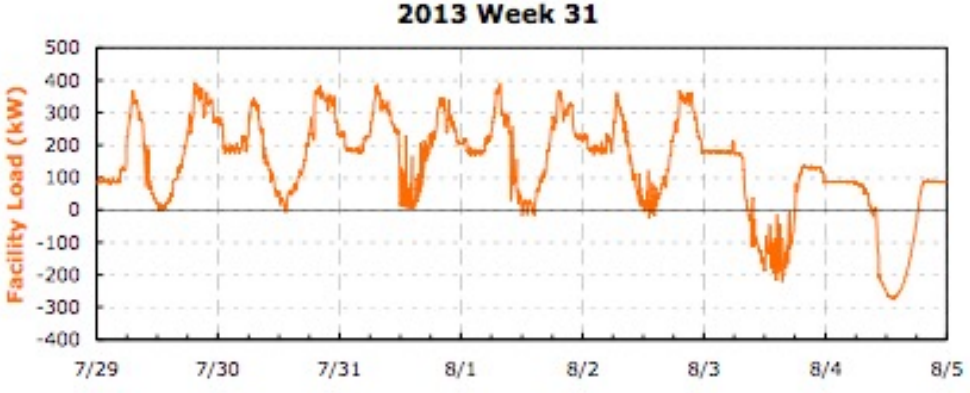
OCC-DVC = OFF

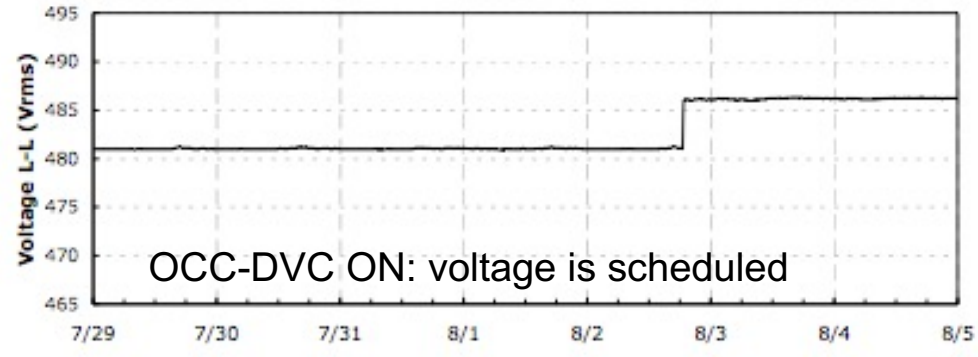


OCC-DVC OFF: wide voltage fluctuation

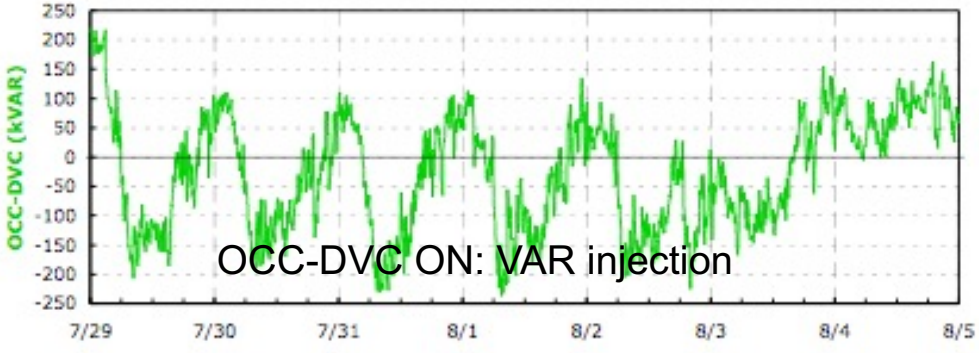


OCC-DVC = ON





OCC-DVC ON: voltage is scheduled



OCC-DVC ON: VAR injection

OCC-DVC (Dynamic Load&PV)

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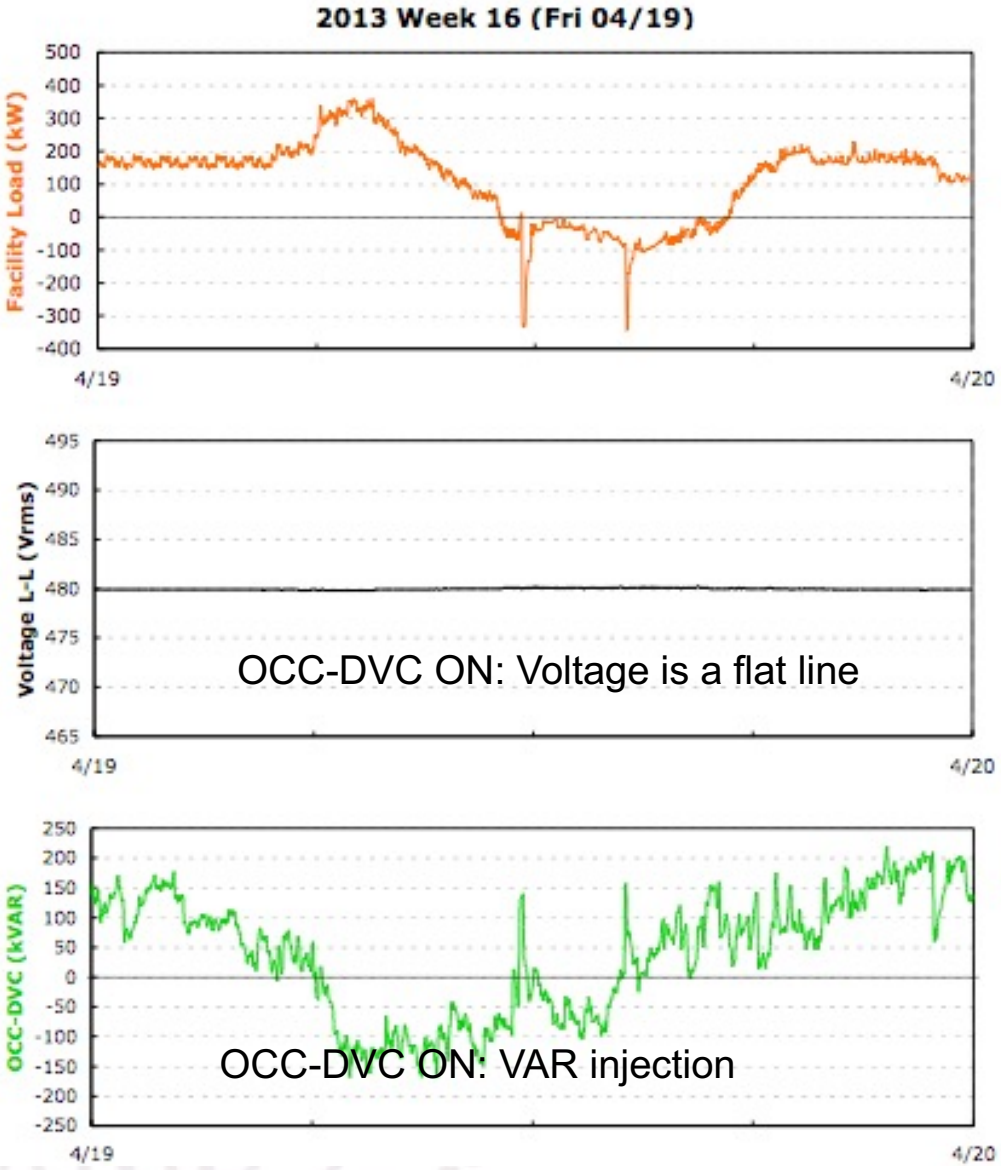
2 load drops ➔
Solar power surges back to transformer

Voltage is stabilized

OCC-DVC fast action
To combat the transient



October 18, 2013, 9:03AM

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

Duke Energy Installation

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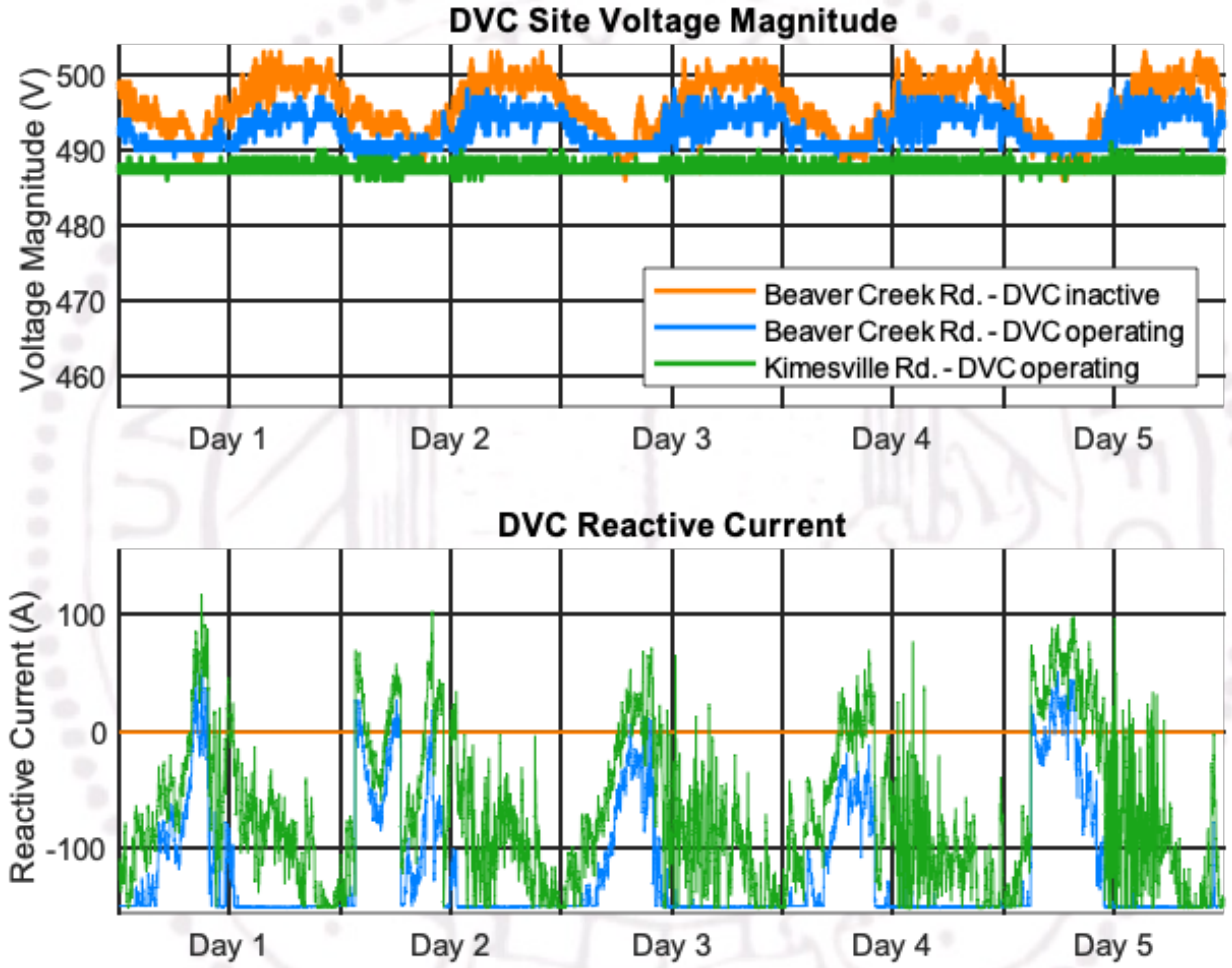

Source: Duke Energy

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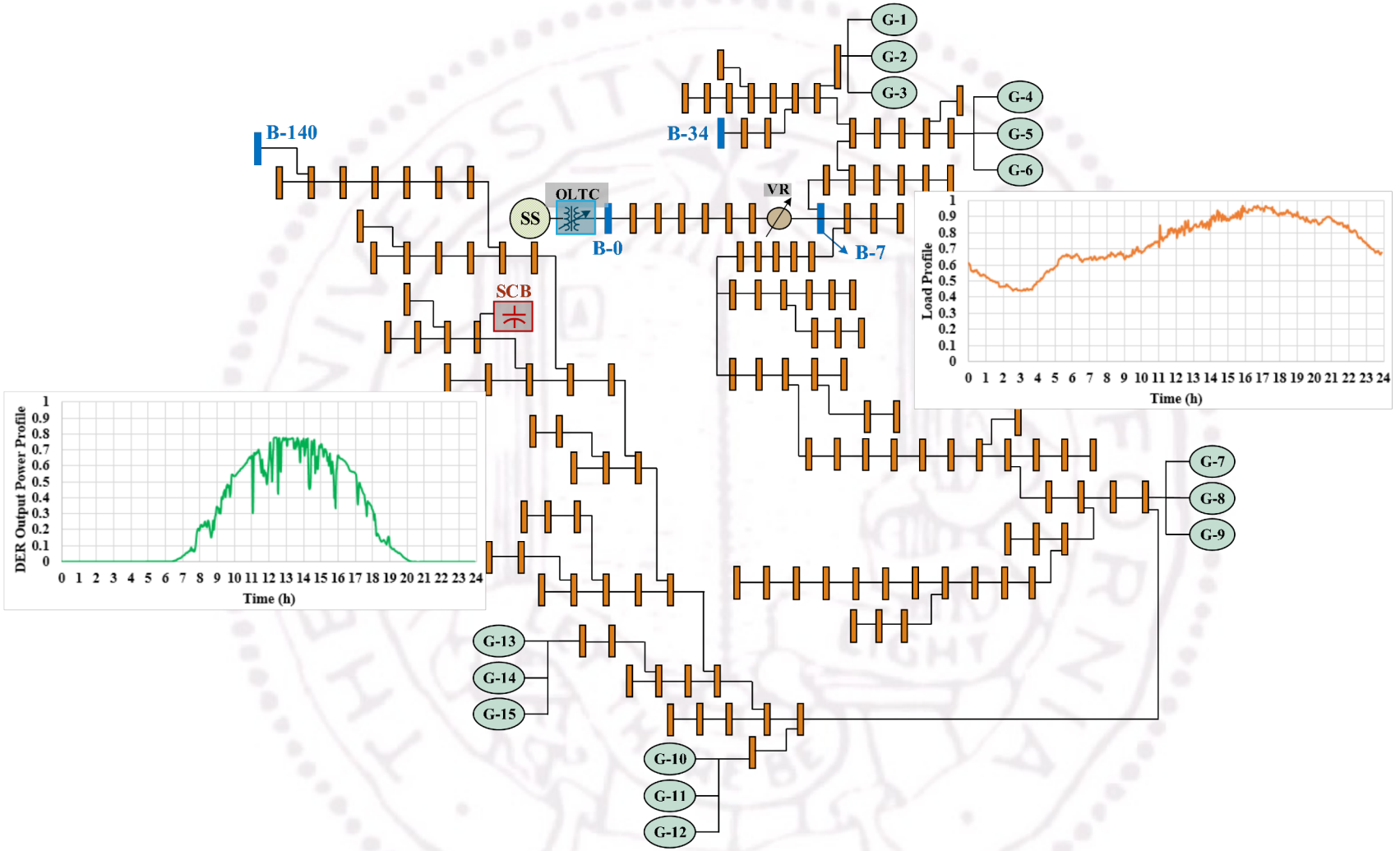
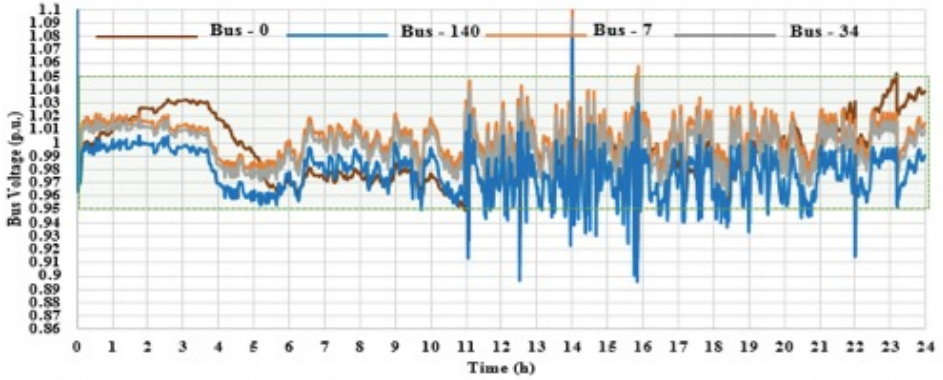
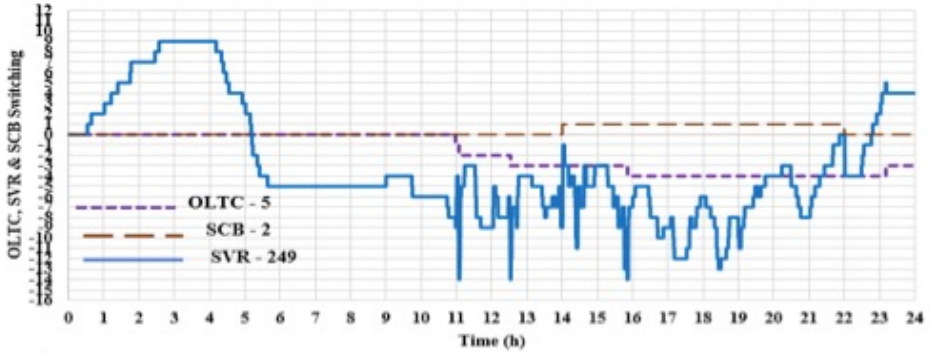
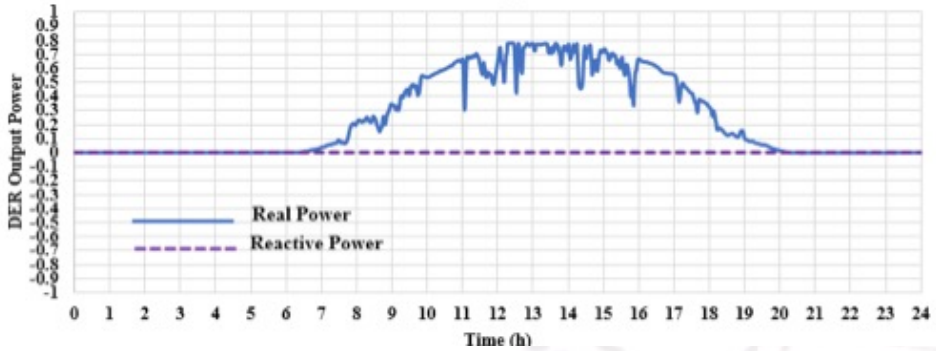
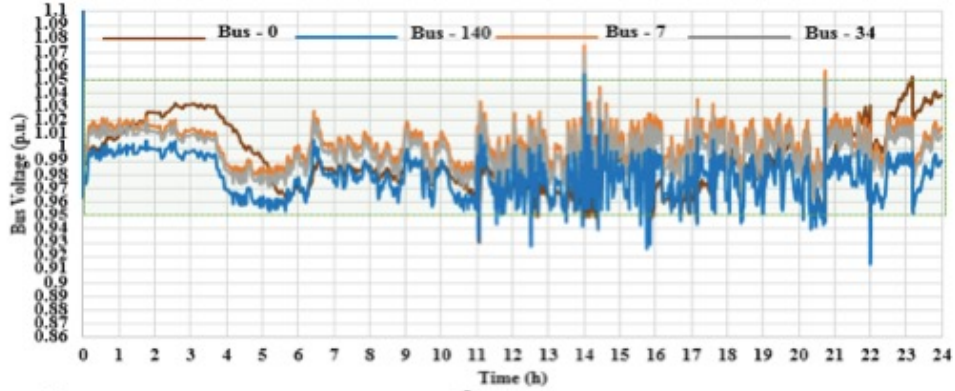


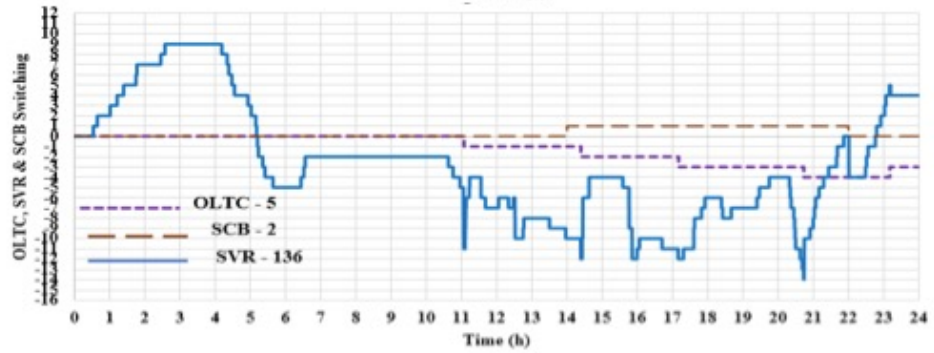
140 bus SCE DPS simulation of coordination of Fast VAR

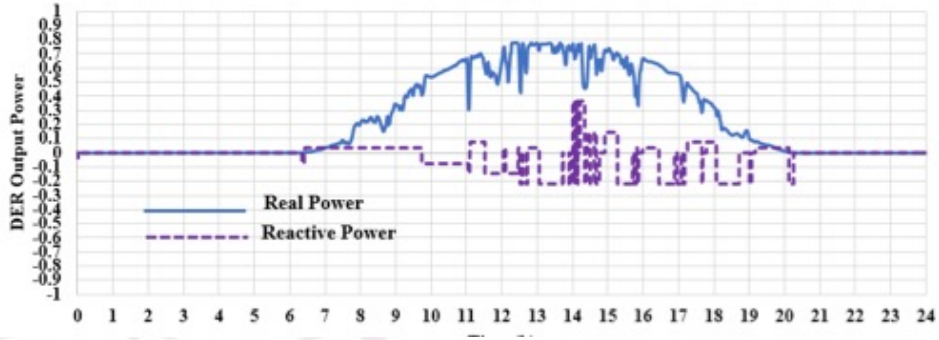












No reactive injection
Frequent transient activities

With reactive injection
Smoother operation

VAR & Voltage Regulation Method Comparison

- Synchronous condenser: high inertial not suitable for fast transient intermittency
- Switching capacitor and LTC: slow speed and step control
- SVC: too slow to capture the fast transient of renewables
- STATCON: may be able to handle when the transient is mild
- OCC-DVC has demonstrated fast transient suppressing capability
- Opportunity: OCC-DVC coordination with LTC, Switching Cap, and SVC ➔ smooth and cost-effective solutions.

OCC-DVC

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Enables high penetration