Utility Scale Solar PV Project Experience

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Outline

- Utility Scale Solar PV
  - Introduction to SunPower
  - SunPower Project Examples
  - OASIS: Tracking Solar PV Power Plant Blocks
- Grid Integration of Solar PV
  - Voltage Support
  - Fault Ride Through
  - Active Power Management
  - Frequency Support
  - System Impact Studies

SunPower 2011 – The World's Standard for Solar

- 2010: Revenue $2.15-$2.25B
- 5,500+ Employees
- 550+ MW 2010 production
- >1.5 GW solar PV deployed
- 5 GW power plant pipeline
- World-leading solar conversion efficiency
- Diversified portfolio: roofs to power plants
- 1,500 dealer partners, #1 R&C USA

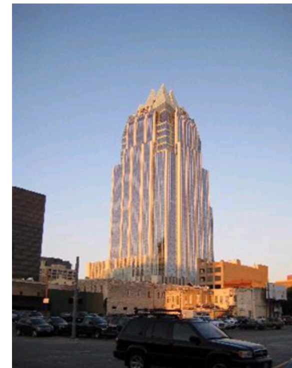
Residential

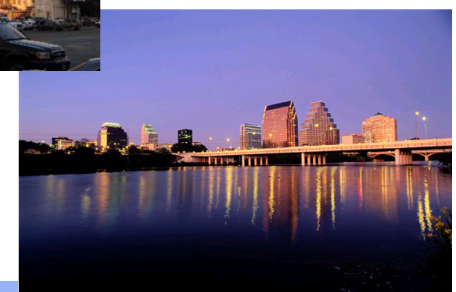
Commercial

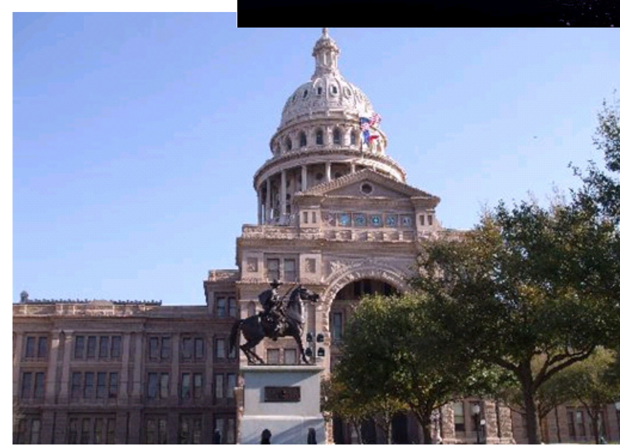
Power Plants

SunPower To Open Operations Center in Austin, TX

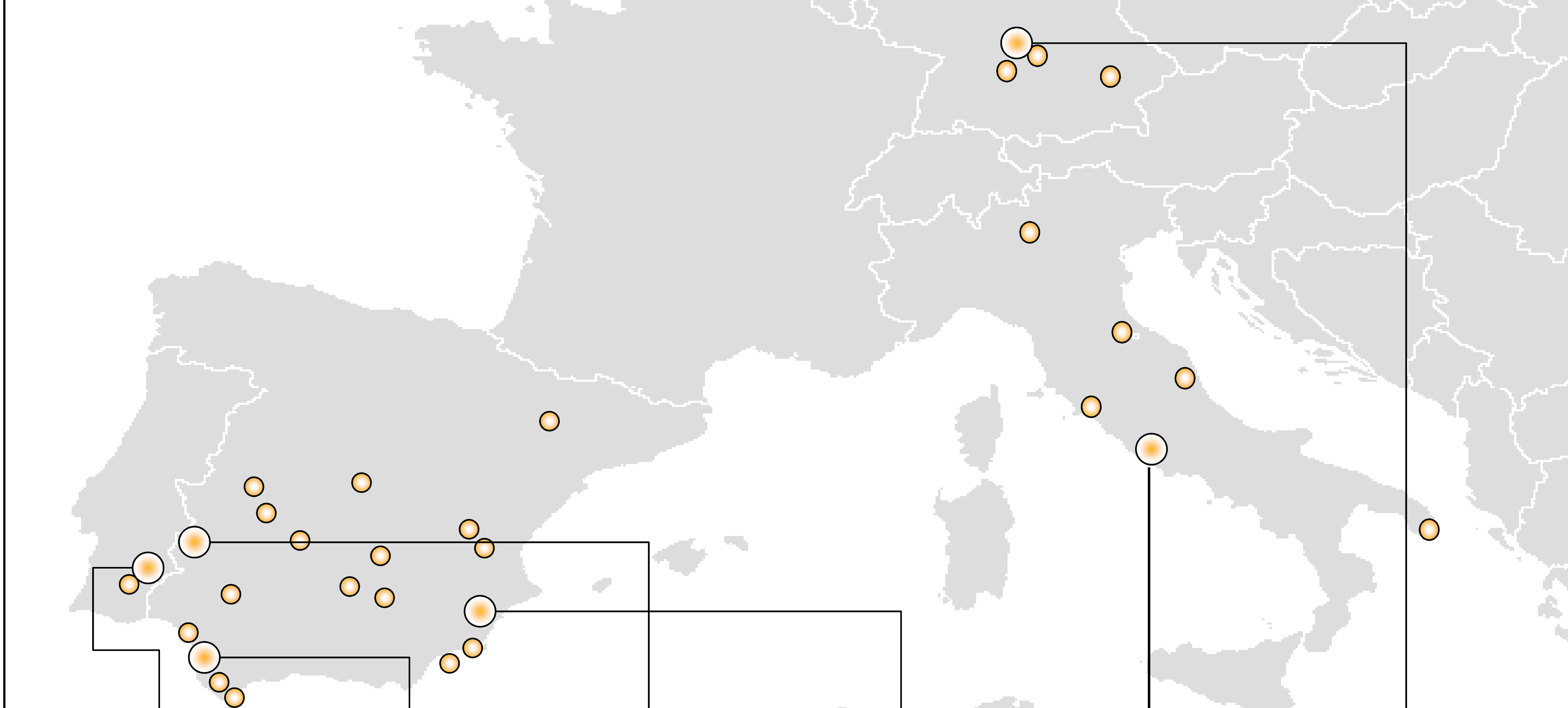
- SunPower is expanding into Texas with a new operations center in Austin
- SunPower will create 450 jobs in the region by 2015, beginning with 115 jobs created in 2011
- The new Austin facility will house operations including marketing, legal, and finance functions







Over 250 MW of power plants installed in Europe



Serpa, PORTUGAL
11 MW

Isla Mayor, SPAIN
8 MW

Olivenza, SPAIN
18 MW

Jumilla, SPAIN
23 MW

Montalto, ITALY
72 MW

Muehlhausen, GERMANY, 6 MW

SunPower Utility Solar PV Power Plants

- **Examples of Project Experience**

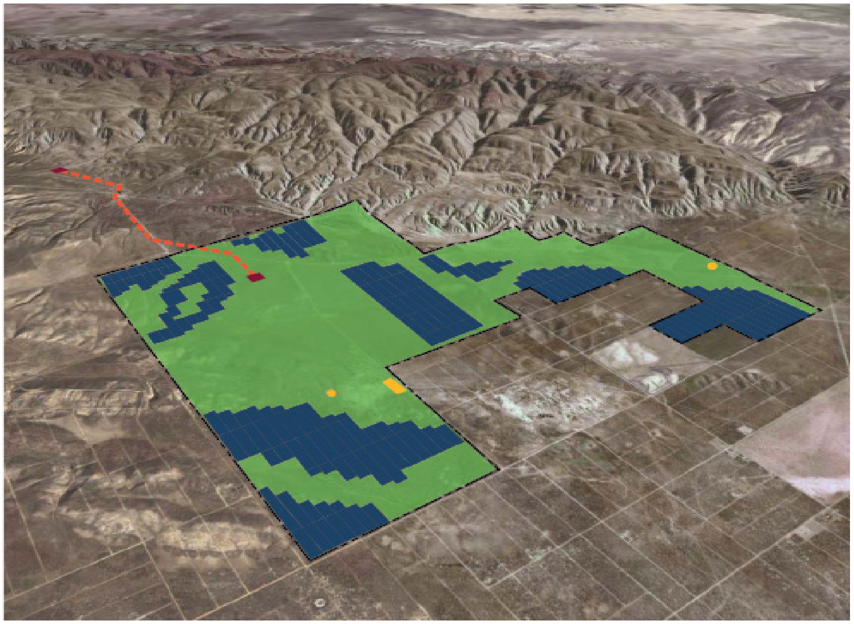
YEAR	MARKET	MW	NAME
2004	Germany	10	Solar Bavaria
2006	Portugal	11	Serpa
2007	U.S. - Nevada	14	Nellis Air Force Base
2008	Spain	18	Olivenza
2009	U.S. - Florida	35	DeSoto (FPL)
2010	Italy	72	Montalto di Castro
2010	U.S. - Colorado	19	Greater Sandhill (Xcel)
2011	U.S.- California	250	CVSR (PG&E)

Montalto 72 MW
Lazio, Italy

Nellis AFB 14 MW: NV energy
Las Vegas, NV, U.S.

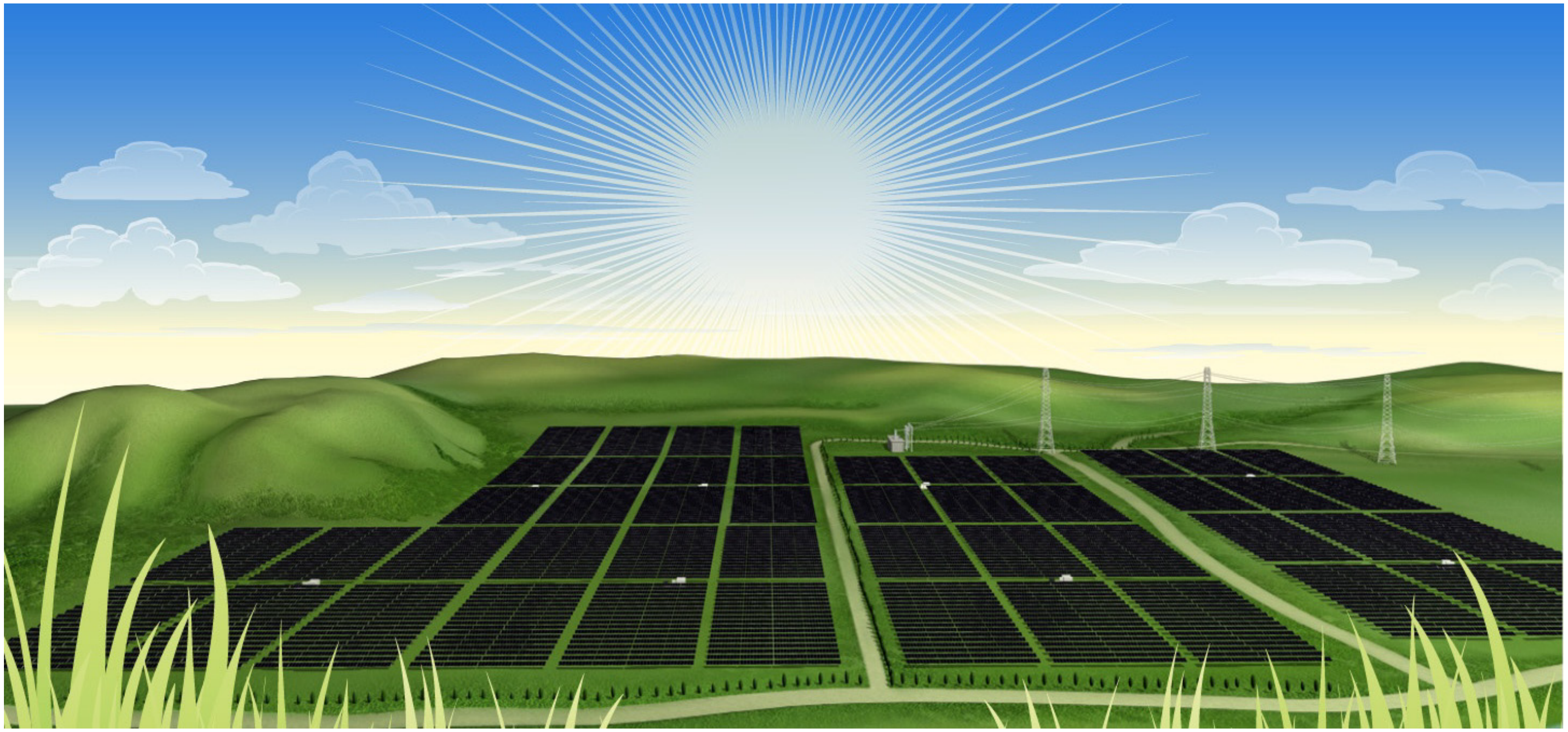
Greater Sandhill 19 MW: Xcel
Alamosa County, Colorado, U.S.

California Valley Solar Ranch (CVSR)



- 250 MW PPA with PG&E
- Target Schedule
  - Q3/Q4 2011 – Start of Construction
  - Q4 2011/Q1 2012 – Phase I Complete/First 25MW on-line
  - Q4/2013 – Project Completion
- Permit recently approved by San Luis Obispo county supervisors 5-0

SunPower Oasis Power Plant



The SunPower Oasis power plant is a modular utility solar platform consisting of configurable 1.5 MW PV power blocks coupled with a sophisticated plant operating system

The SunPower Oasis Tracker & 425 W Panel

SunPower T0 Tracker

Most installed solar tracker in the world – 400MW over 10 years

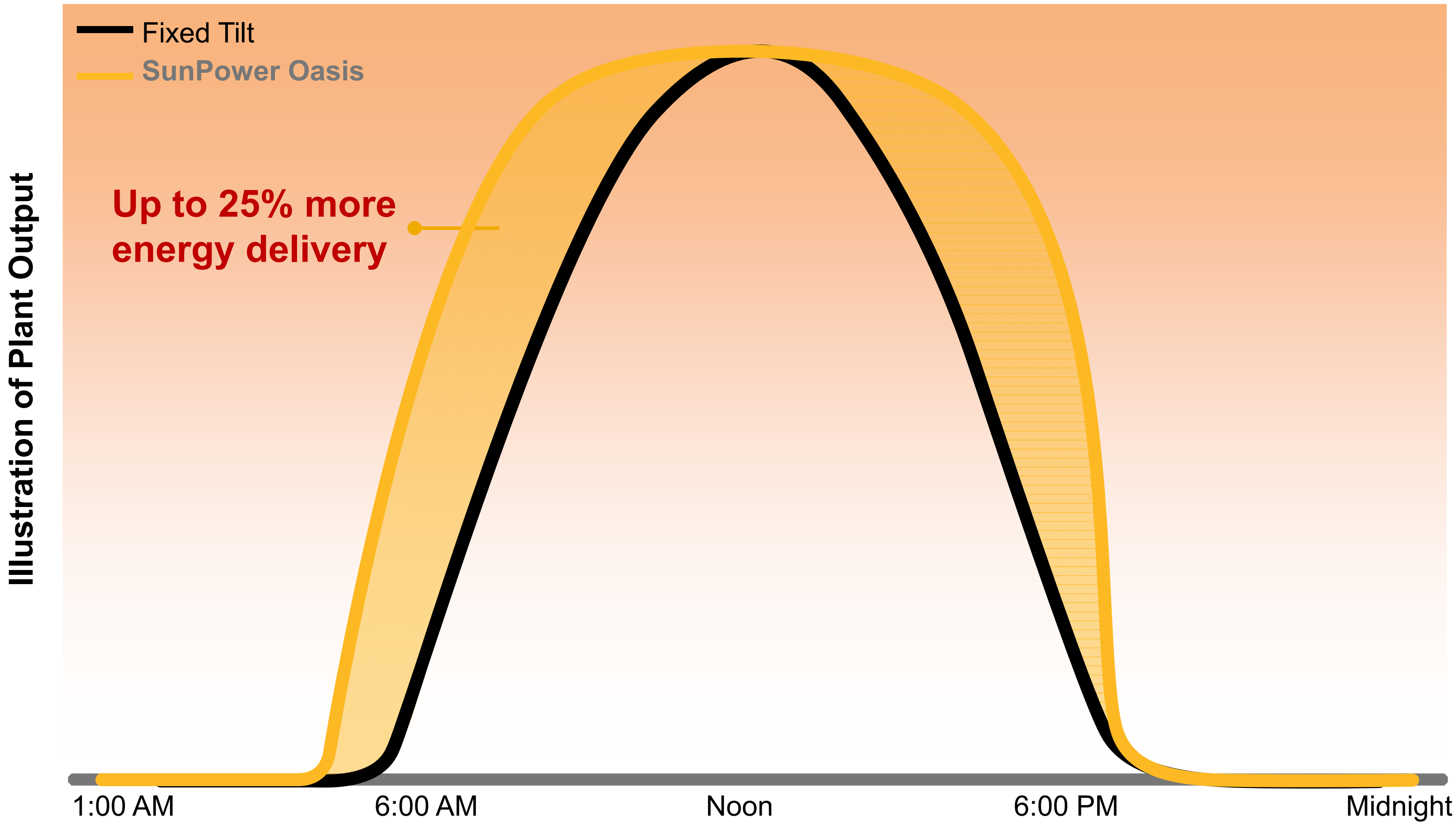
Increases capacity factor by up to 25%

Simple control system = lowest O&M of any PV power plant fixed or tracking

SunPower 425W panel has today's highest efficiency

Jeonju, Korea
2 MW

Oasis Power Block Enhances Production



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  - SunPower Project Examples
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- Grid Integration of Solar PV
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  - Fault Ride Through
  - Active Power Management
  - Frequency Support
  - System Impact Studies

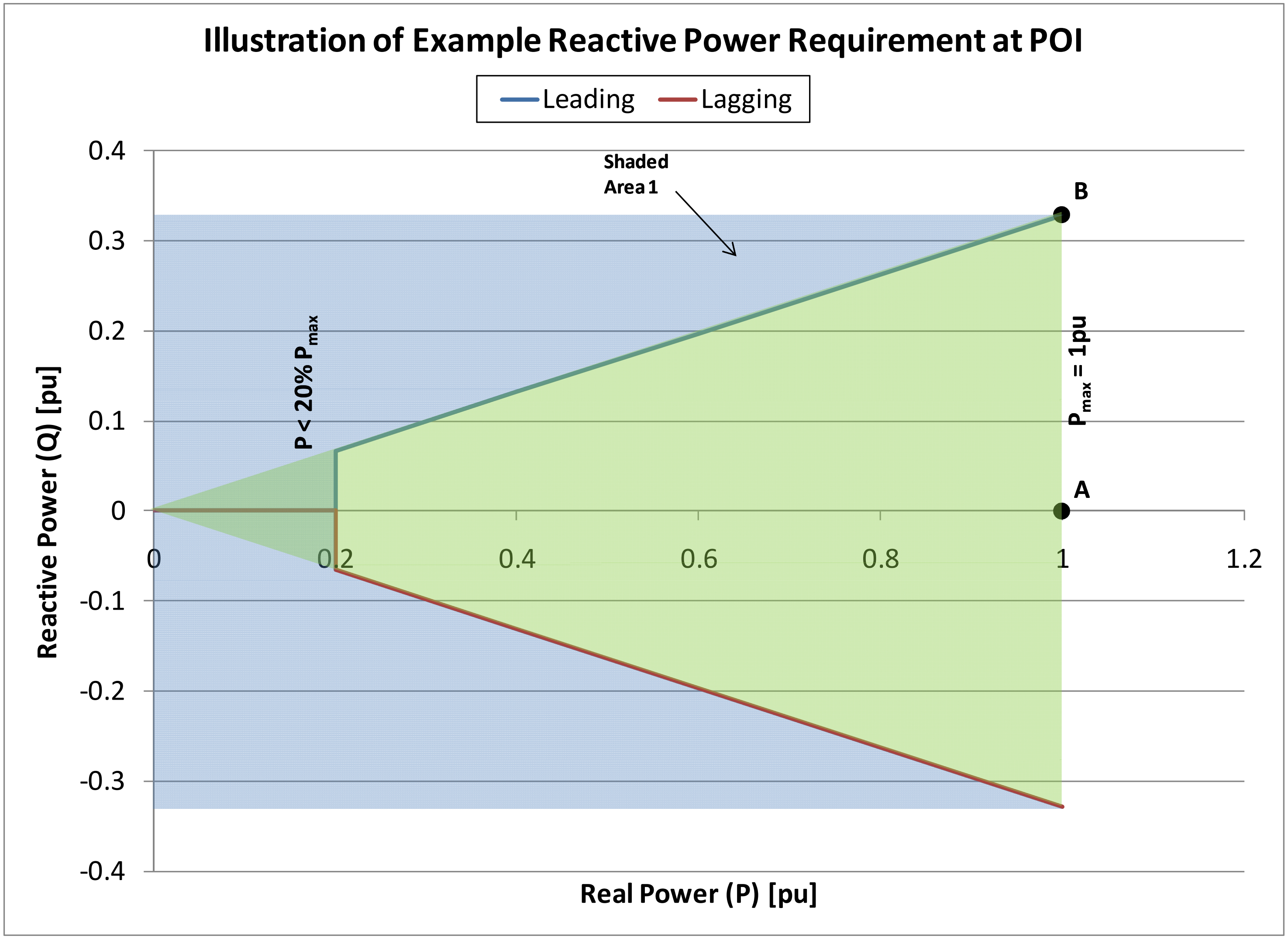
Progress in Solar PV Integration

- Solar PV's initial application was residential and commercial
  - Standards (UL1741, IEEE 1547) intended for distribution networks
  - Inverters for use on distribution networks initially designed without LVRT, voltage control, etc. to meet these requirements
- SunPower Utility Scale PV plants have the technical capabilities to provide features similar to modern wind plants:
  - Ride Through (Voltage and Frequency)
  - Over Frequency Droop Response
  - Real Power Curtailment
  - Reactive Power Support
- Grid integration products in the market are evolving

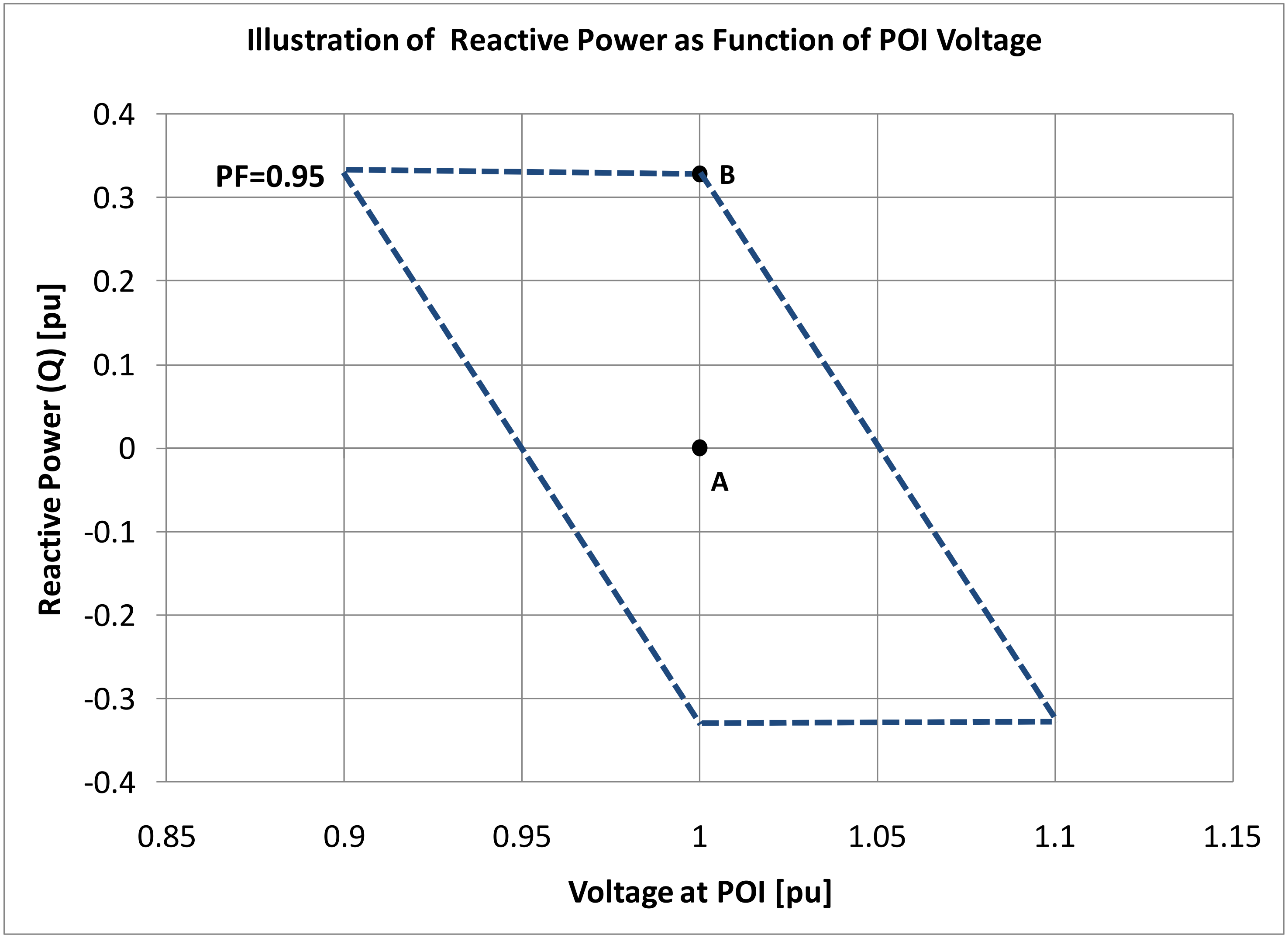
OASIS Grid Integration Options

- Reactive Power
  - +/- 0.95 PF at POI
  - Voltage, Power Factor, or Reactive Power Control
- Fault Ride-Through
  - Configurable Voltage and Frequency Ride though Windows
- Over Frequency Droop Response
- Active Power Curtailment from 0 to 100%

Reactive Power Requirements



Reactive Power as Function of Voltage at POI



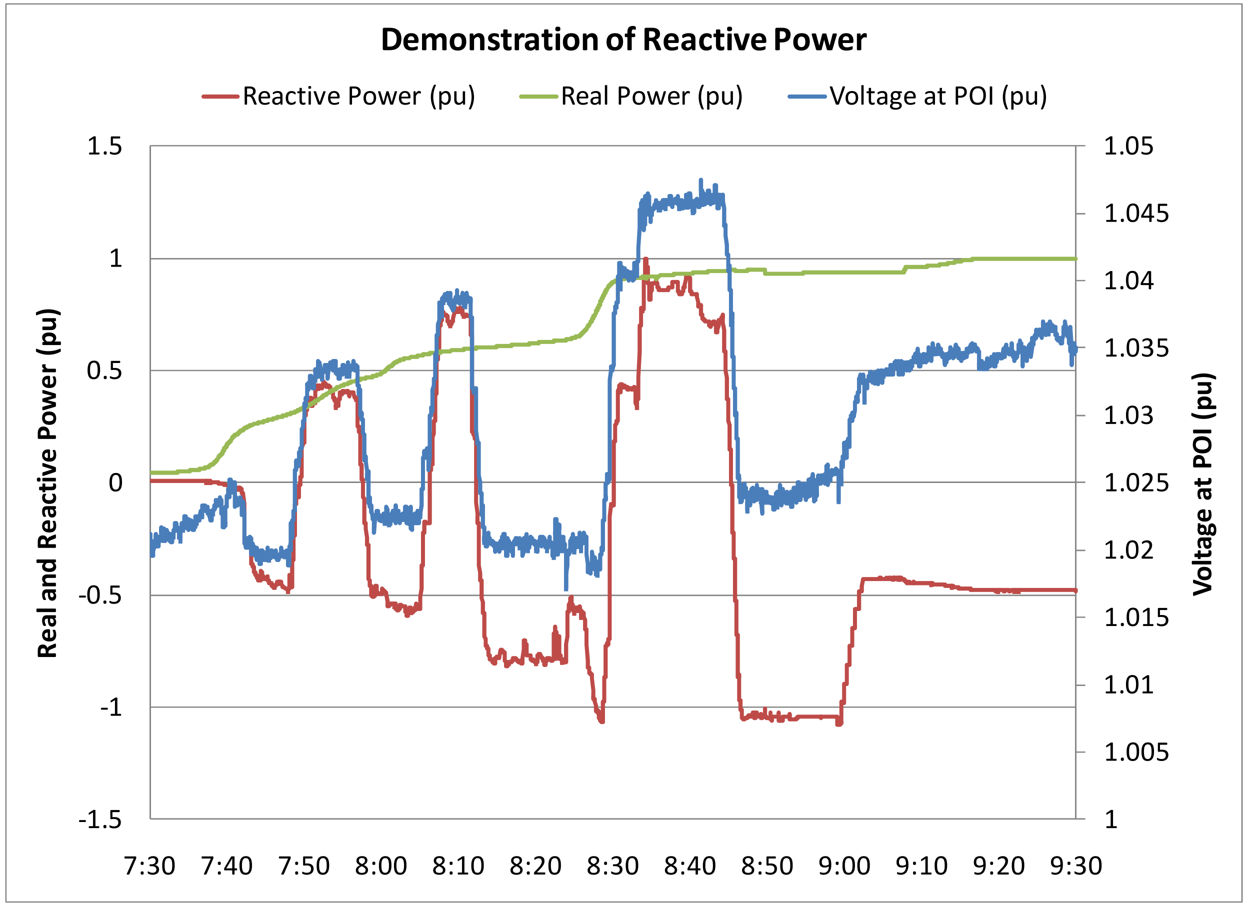
Example Reactive Power Testing Procedures

Test	Condition	Test	Requirement
Maintain voltage setpoint	P = 25% to >92.5% of Available Capacity	Set voltage setpoint to 1.02 pu	Voltage held within +/- 1%, subject to p.f. limits and Available Capacity. New voltage setpoint(s) may be selected.
Compensate for changing transmission conditions	Q = ~0 MVAR output after LTC is adjusted several steps	Set voltage setpoint as necessary	Q <=0 MVAR at POI
Lead/Lag 0.95 limits	P = 25%, 50%, 75% and >92.5% of Available Capacity, limited to 9.4 MVAR at POI.	Set voltage to demonstrate 0.95 p.f. Lead	Meter shop test equipment indicates 0.95 or less
		Set voltage to demonstrate 0.95 p.f. Lag	Meter shop test equipment indicates 0.95 or less
Raise/lower setpoint	P > 50% of Available Capacity	Series selected at time of test (ex: Raise/Lower voltage 0.005pu)	Voltage at POI is consistent with change in setpoint, subject to p.f. limits and within the ability of the plant to influence the voltage

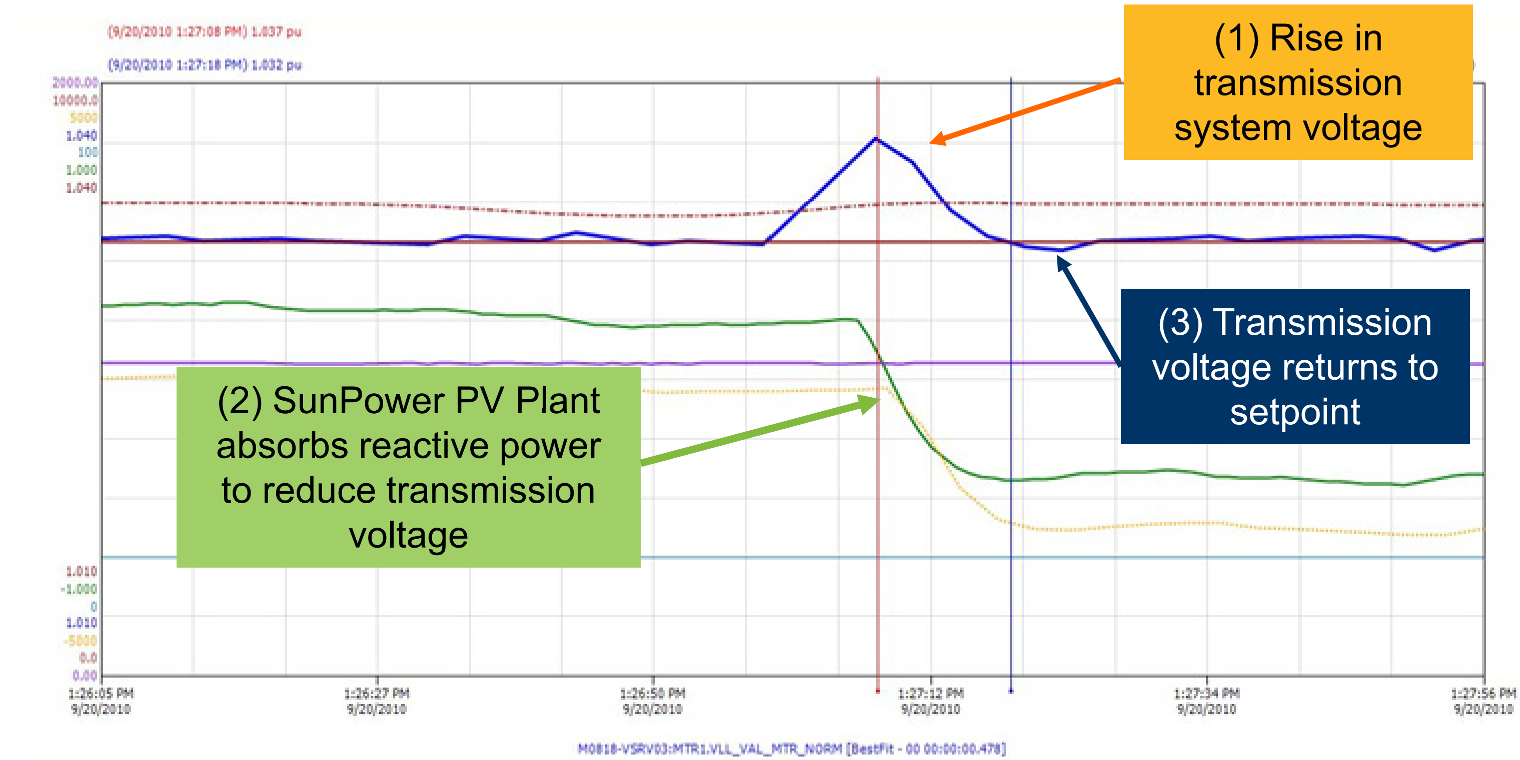
- Available Capacity = Total plant power output correcting for environmental variables (e.g. irradiance, temperature).

Example of Test Demonstration

- Successful test of reactive power tests for SunPower Utility Scale Solar PV Plant
- Demonstrated at range of Power outputs during the morning
- Reaches Full Reactive Power Requirements (+/- 0.95 pf)



Voltage Control



SunPower PV Plant operational in North America with automated voltage control on the transmission system

Summary of Reactive Power Requirements

- SunPower Utility Scale PV Plants have demonstrated ability to provide reactive power support and help maintain voltage

- Shared goal of grid reliability and stability
  - Requirements that are designed to promote grid stability and reliability while avoiding market barriers
  - Utility Testing and Operational Requirements

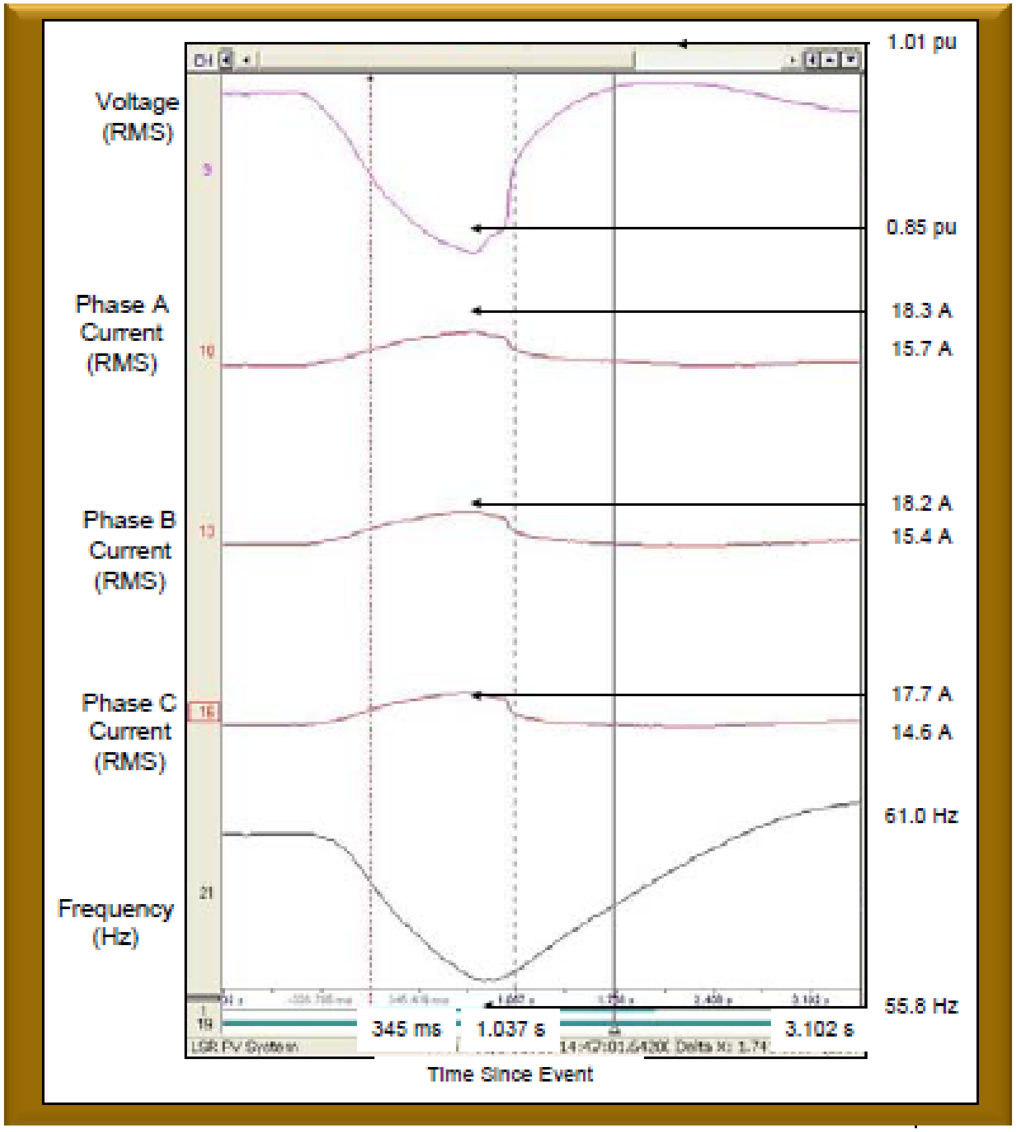
Regulatory Ride Through Requirements

- Rules on Ride through still evolving in U.S. and elsewhere
  - OASIS has configurable Voltage and Frequency Ride though Windows
  - Ex: FERC Order 661-A, NERC PRC-024 (Draft), WECC ONF, MV BDEW
- Example of LVRT Requirement: Ride through three phase faults on transmission grid with normal clearing times (4-9 cycles)

WECC Off-Nominal Frequency (ONF) Tolerance		
Under-frequency Limit	**Over-frequency Limit**	**WECC Minimum Time**
> 59.4 Hz	60 Hz to < 60.6 Hz	N/A (continuous operation)
≤ 59.4 Hz	≥60.6 Hz	3 minutes
≤ 58.4 Hz	≥61.6 Hz	30 seconds
≤57.8 Hz		7.5 seconds
≤57.3 Hz		45 cycles
≤57 Hz	>61.7 Hz	Instantaneous trip

Ride Through

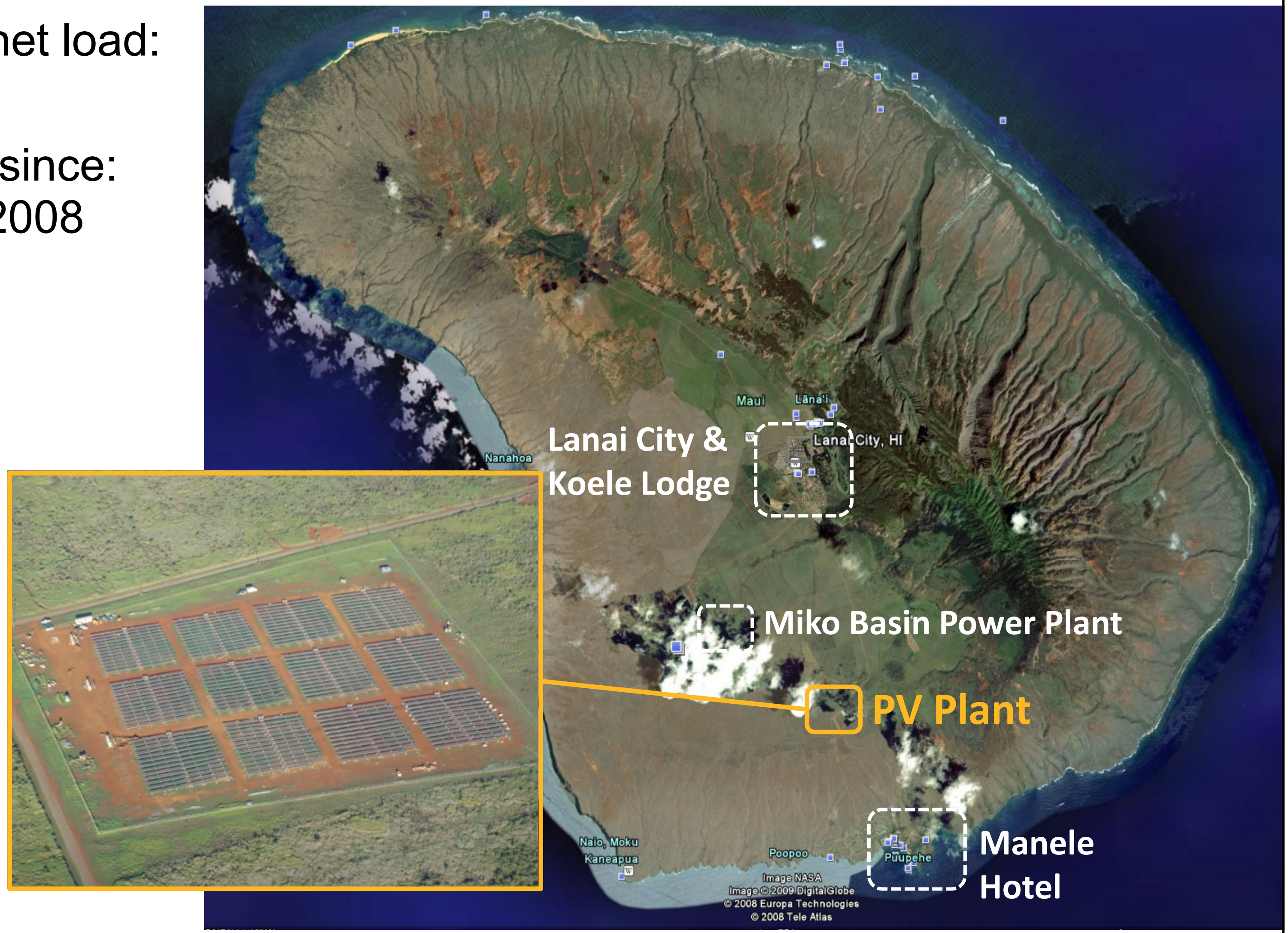
- Example of operational SunPower Solar PV Plant riding through a disturbance
- Voltage and Frequency Ride Through
- Plant remains online and continues providing power as the grid recovers



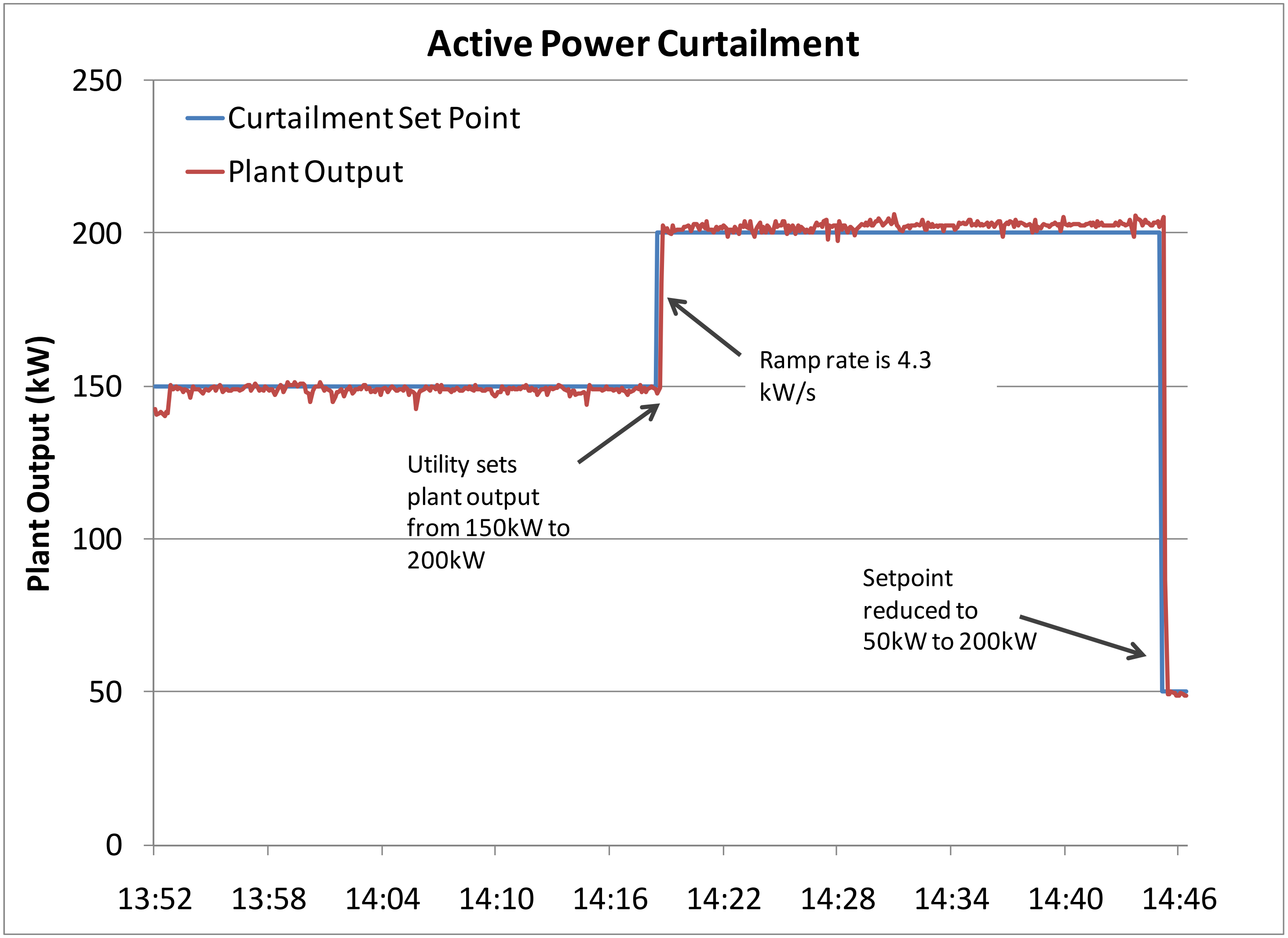
See: "METHODS OF INTEGRATING A HIGH PENETRATION PHOTOVOLTAIC POWER PLANT INTO A MICRO GRID", Lars Johnson, 35thIEEE PVSC, Honolulu, Hawaii, June 2010.

Lanai (Hawaii) 1.2 MW Project

- Lanai peak net load: 4.7 MW
- Operational since: December, 2008



Example of Active Power Curtailment

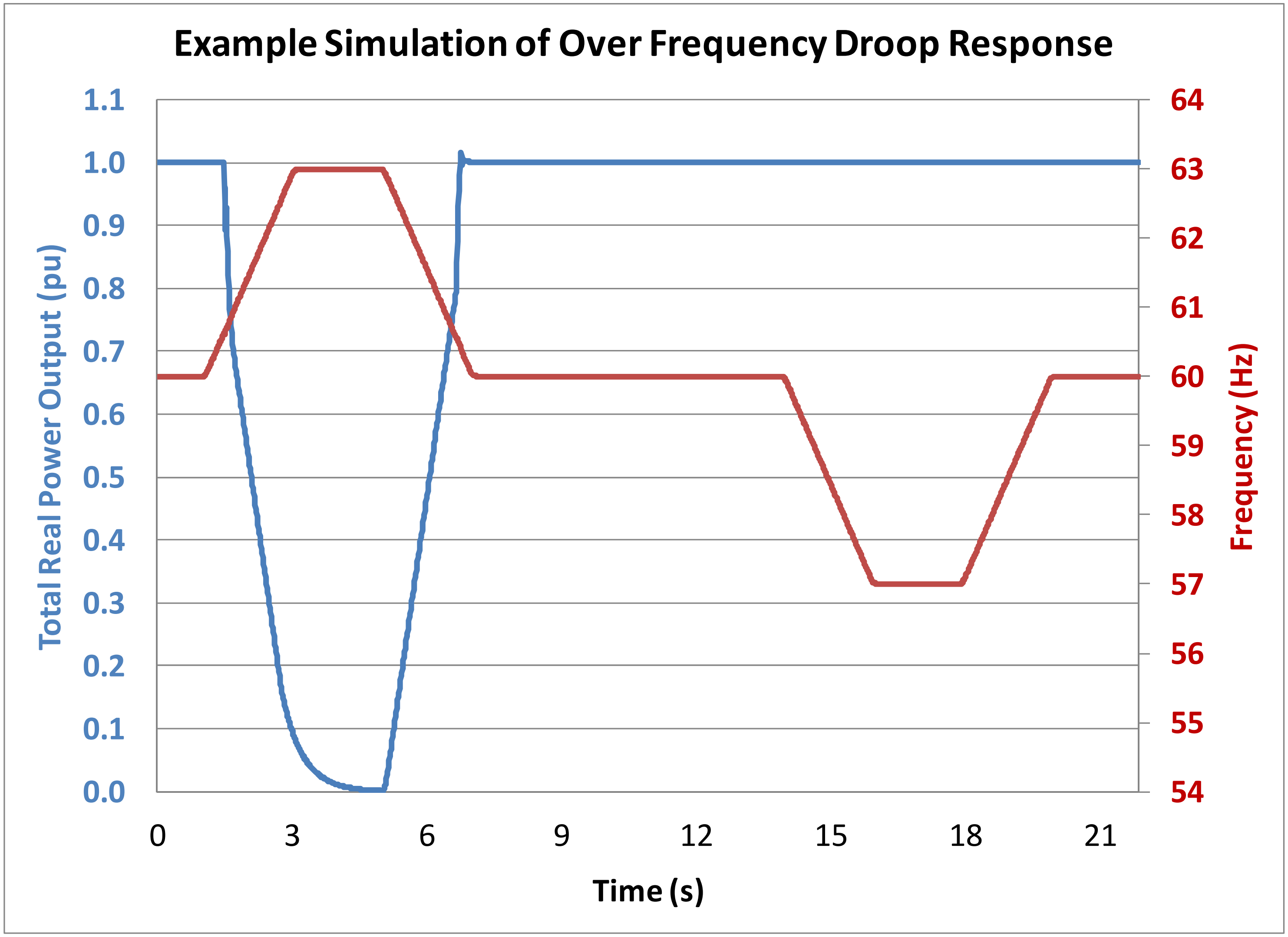


See: "METHODS OF INTEGRATING A HIGH PENETRATION PHOTOVOLTAIC POWER PLANT INTO A MICRO GRID", Johnson R, Johnson L, Nelson L, Lenox C, Stein J.

Over Frequency Droop

- OASIS has the option of a configurable droop response
- Example: Project currently in late stage development
  - Project expected to start construction this year
  - Specific voltage and frequency issues for local grid
  - Utility interested in option of Over-Frequency Droop Response
- Not aware of any requirements for over frequency droop for a currently operational Solar PV Plant in U.S.

Example Simulation: Over Frequency Droop



System Impact Studies for Solar PV Plants

- Assess impacts on system reliability and stability
- California ISO Cluster Process
  - Over 16,000 MWs of Solar PV in Interconnection Queue
  - Power flow, dynamic stability, and short circuit studies
- SunPower has provided Plant Level Equivalent Models for System Impact Studies
  - Proprietary positive sequence models (PSSE/PSLF) exist today for Solar PV inverters
  - WECC Renewable Energy Modeling Task Force (REMTF)

Summary of Grid Support

- SunPower Utility Scale PV plants have demonstrated ability to provide:
  - Voltage Support
  - Ride through disturbances on the grid
  - Active power management
  - Over frequency droop response

- Models of Solar PV Plants available for System Impact Studies

- Shared goal of requirements that promote grid reliability and stability while avoiding market barriers

Summary

- Thank you for the opportunity to present our experiences!
- SunPower has over 1.5 GW of solar PV deployed worldwide
- The OASIS Power Plant with grid integration options:
  - Ride Through (Voltage and Frequency)
  - Over Frequency Droop Response
  - Real Power Curtailment
  - Reactive Power Support
- A thank you for all the helpful support to: Kari Smith, Alan Comnes, Carl Lenox, Chris Barker, Robert Johnson, Lars Johnson, and many others from the SunPower team
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