Photovoltaics and Electrical Storage

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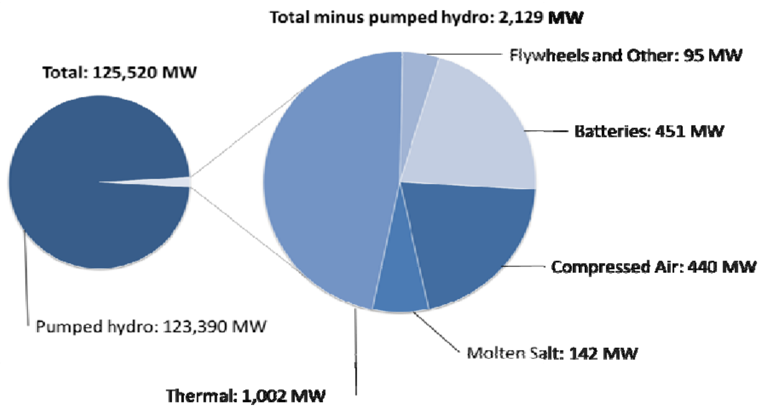
Estimated Global Installed Capacity of Energy Storage (from Energy Storage Associates presentation)



Source: StrateGen Consulting, LLC research; thermal storage installed and announced capacity estimated by Ice Energy and Calmac. Note: Estimates include thermal energy storage for cooling only. Figures current as of April, 2010.

Comparison of Storage Technologies
(Electrical Storage Association)

Storage Technology	Main Advantages	Disadvantages	Power Application	Energy Application
Flow batteries	High capacity, independed power and energy ratings	Low energy density	Reasonable for this application	Fully capable and reasonable
Sodium-sulfur batteries	High power and energy densities, high efficiency	Production cost high, safety concerns	Fully capable and reasonable	Fully capable and reasonable
Li-ion batteries	High power and energy densities, high efficiency	High production cost, requires special charging circuit	Fully capable and reasonable	Feasible, but not quite practical or economical
Other advanced batteries	High power and energy densities, high efficiency	High production cost	Fully capable and reasonable	Feasible, but not quite practical or economical
Lead acid batteries	Low capital cost	Limited life cycle when deeply charged	Fully capable and reasonable	Feasible, but not quite practical or economical
Flywheels	High power	Low energy density	Fully capable and reasonable	Feasible, but not quite practical or economical
Pumped hydro	High capacity, low cost	Special site requirements	Not feasible or economical	Fully capable and reasonable
Compressed air energy storage	High capacity, low cost	Special site requirements, needs gas fuel	Not feasible or economical	Fully capable and reasonable

Global Market Share of Energy Storage Developers

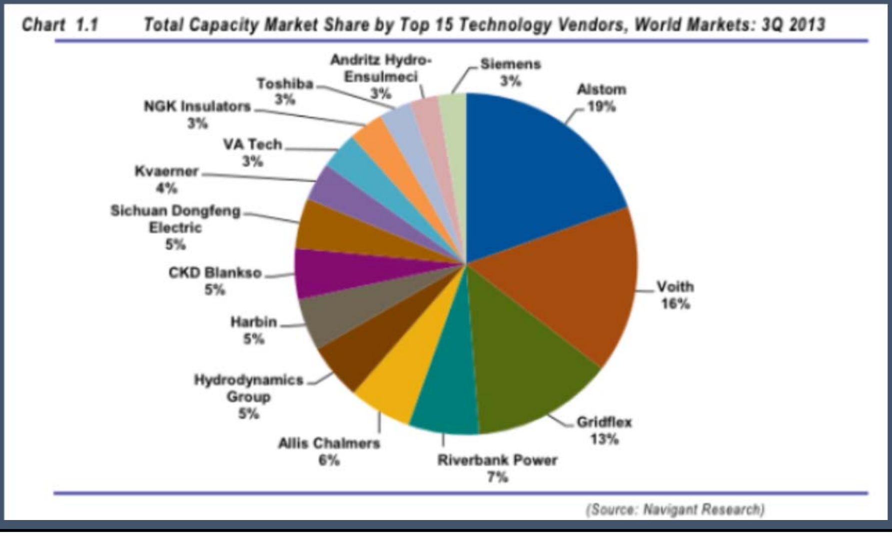


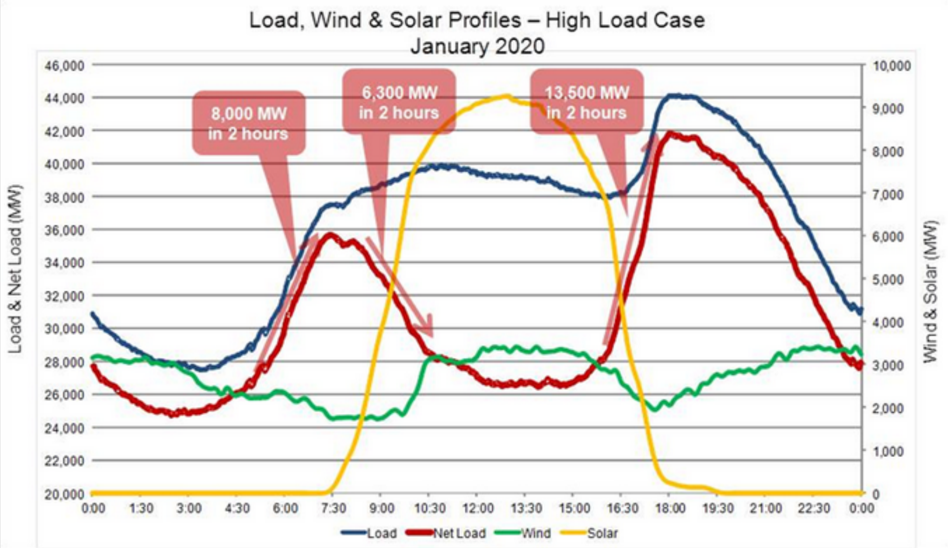
Chart 1.1 *Total Capacity Market Share by Top 15 Technology Vendors, World Markets: 3Q 2013*

(Source: Navigant Research)

Reasons for electrical storage

1. Generation profile ≠ Load profile
   In such a case, some load shifting is required

Example of Different PV Generation and Load



AES Energy Storage

- AES has exceeded 100 Megawatts of installed electrical storage
- Dayton Power and Light 40 MW plant (to the left)
- Most of their projects used sealed battery systems

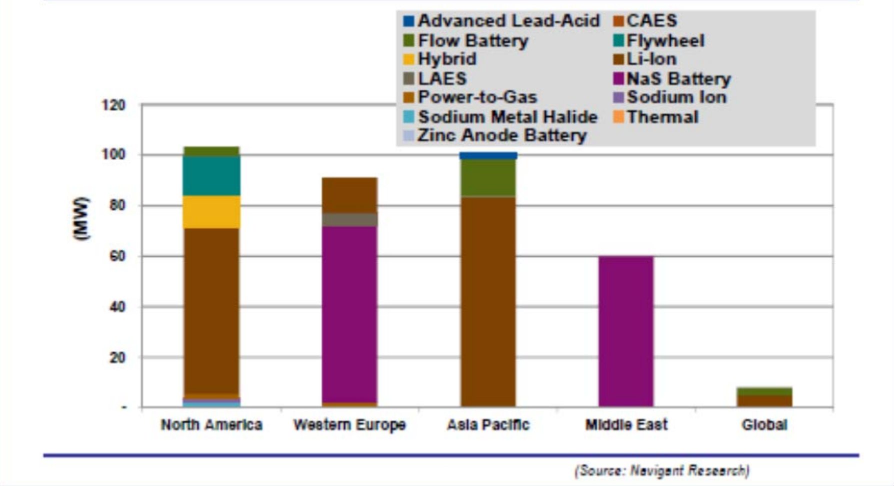


Chart 1.1 New Announced Projects, Excluding Pumped Storage, World Markets: 2013-2014

(Source: Navigant Research)

Reasons for electrical storage

2. Peak shaving is needed to reduce cost of generation

In such a case, some load shifting is required

Example of Peak Shaving with Solar PV

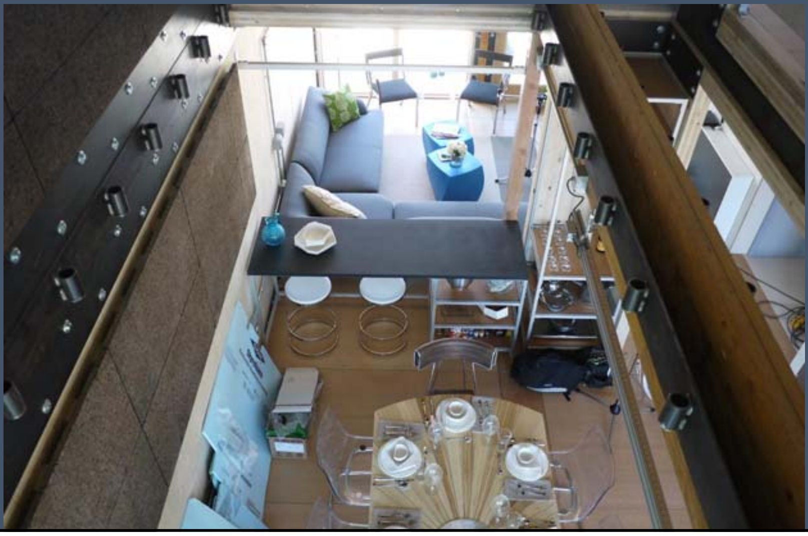
- ❑ Solar Decathlon Europe Project
- ❑ Appalachian State/ University of Angers (Fr) Project
- ❑ Taiwan’s Orchid House
- ❑ Sample rules
    - ❖ Max of 6 kW Photovoltaics
    - ❖ Only receive points if PV production > Electricity consumption
    - ❖ Credit for not using grid electricity between 17:00 and 22:00
    - ❖ Battery storage limited to 5 kWh

ASU/ Angers Solar Decathlon House Under Construction in Boone, NC

House Disassembled

Under Construction in France

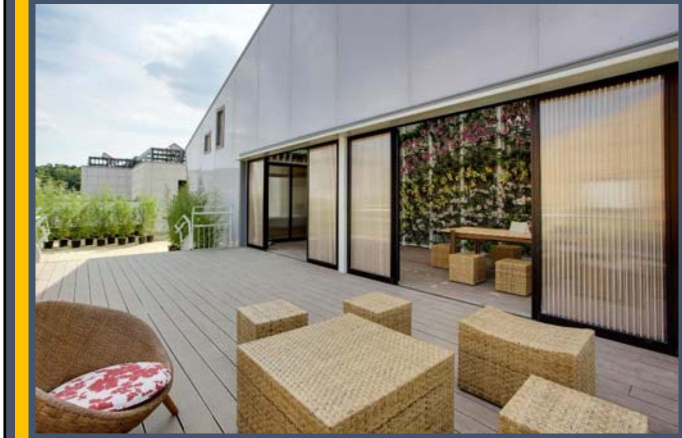
The Interior



Dedication in France

Taiwan Entry in Solar Decathlon 2014: The Orchid House

ORCHID HOUSE



The Taiwan Team Performed Well – 4 trophies!

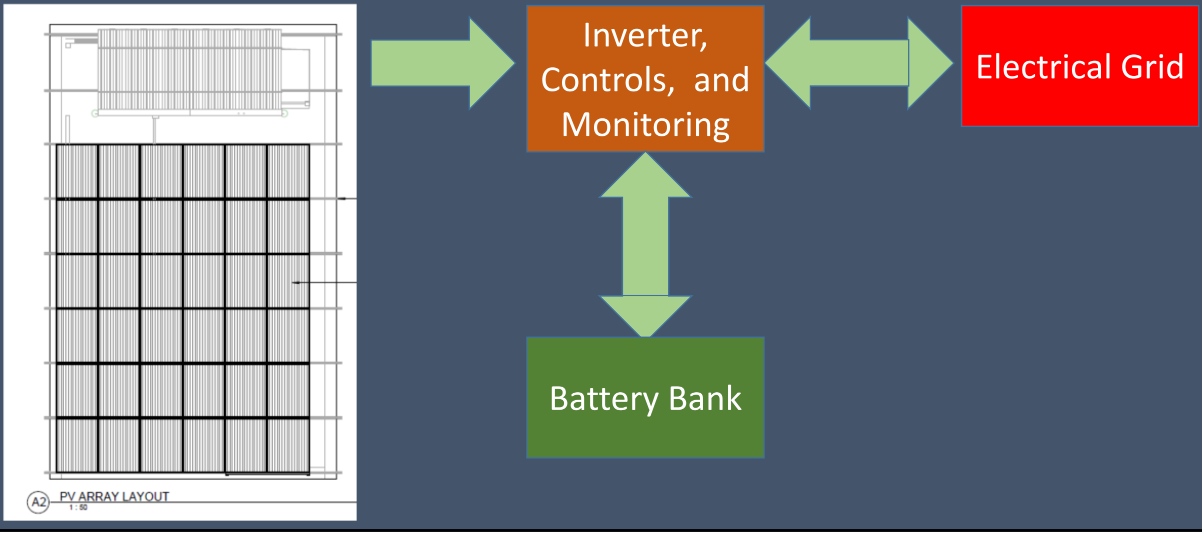
Solar Decathlon Europe 2014:
Key Rules for PV Systems

- Maximum of 5 kW peak
- Commercially available system
- Batteries limited to 6 kWh of storage
- Battery bank inverter < 5 kW

Solar Decathlon Europe 2014 – Points for the following:

- ☐ PV Production > Electricity Consumption
- ☐ Minimize electricity purchased from the electricity grid from 17:00 to 22:00
- ☐ Minimize the power demand (in kW) relative to the power supplied (in kW) by the PV system
- ☐ Maintain temperature and relative humidity in the house throughout the monitoring period

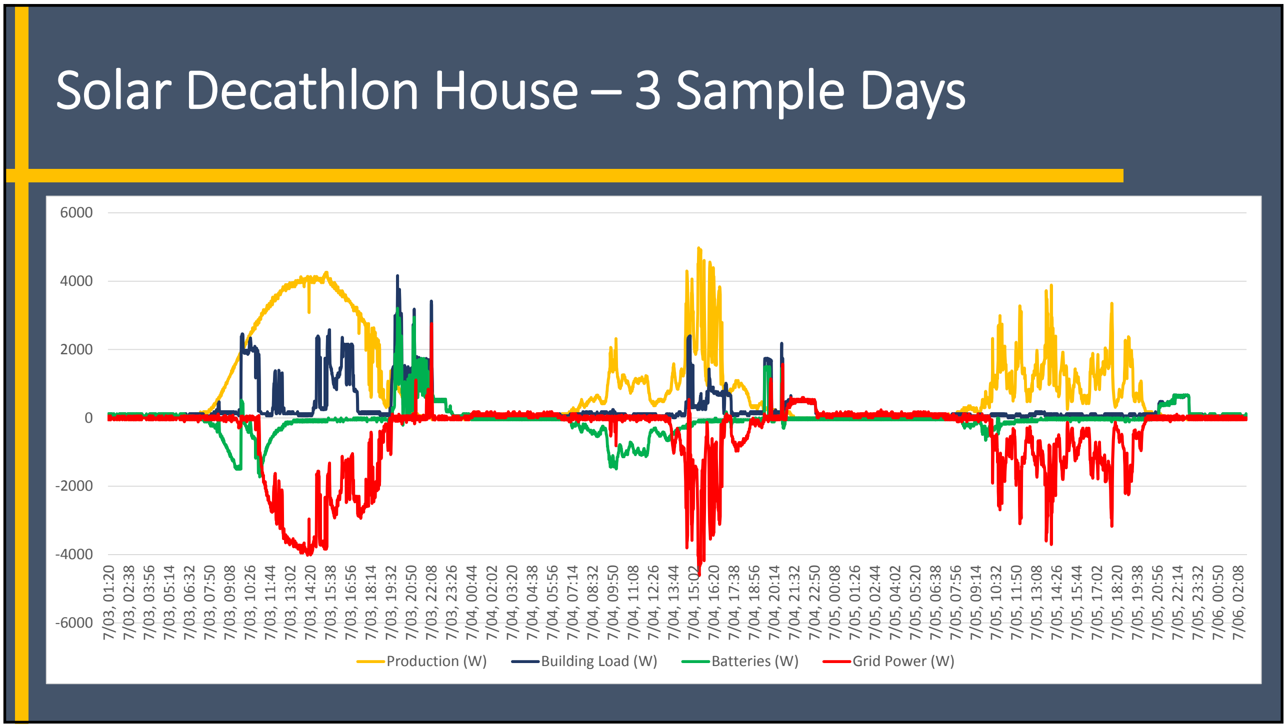
Simplified PV System for Solar Decathlon Project



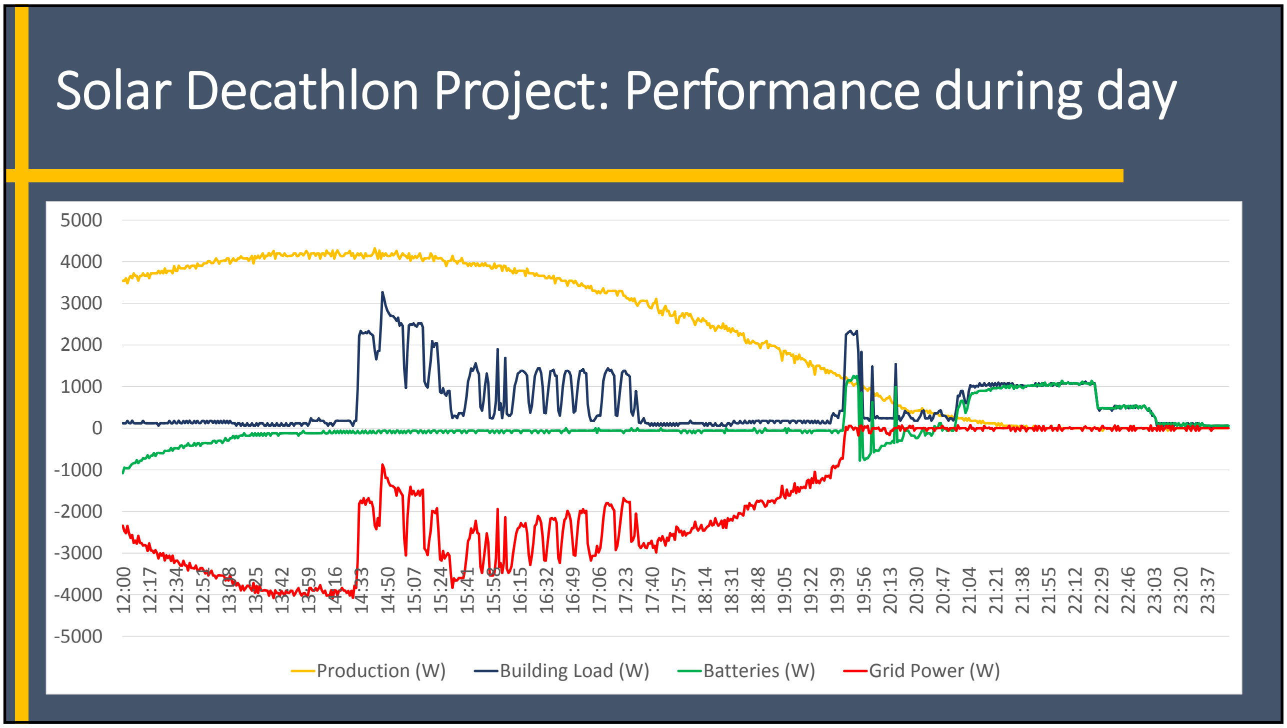
Inverter, Controls, and Monitoring

Electrical Grid

Battery Bank

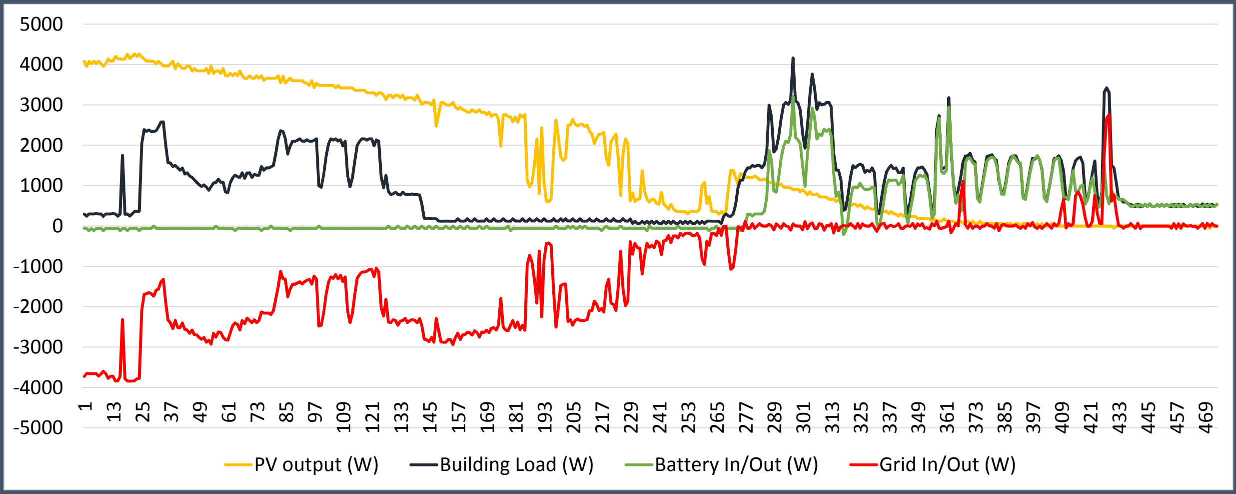


Solar Decathlon House – 3 Sample Days



Solar Decathlon Project: Performance during day

Solar Decathlon Project: Performance at end of day

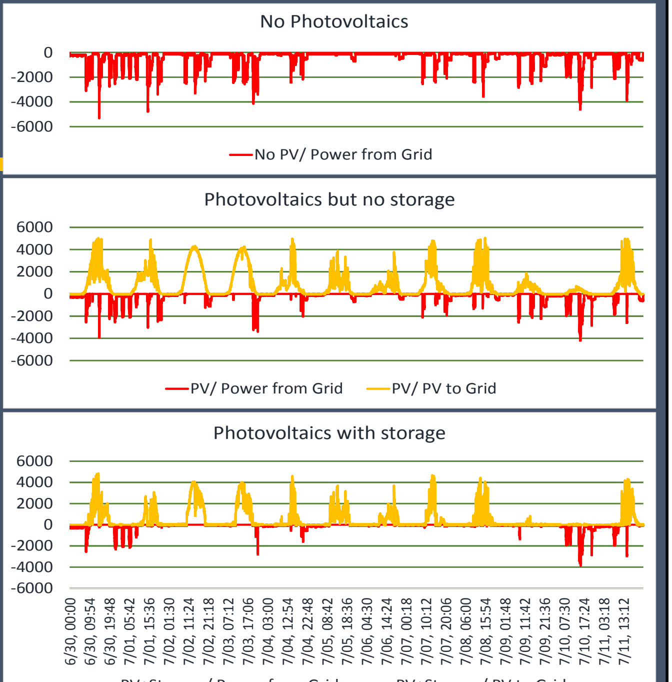


ASU Solar Decathlon House Performance with Integrated Storage

Day	Building Load (kWh)	PV Production (kWh)	Grid Power Used (kWh)	Power Sent to Grid (kWh)	Battery Draws (kWh)
30-Jun	18.0	23.9	5.7	13.3	4.1
1-Jul	15.5	20.1	4.6	6.8	4.0
2-Jul	10.2	35.4	0.2	23.0	2.6
3-Jul	12.8	33.3	0.4	21.3	4.2
4-Jul	5.4	15.0	1.8	6.8	0.6
5-Jul	2.7	13.4	0.7	11.1	1.1
6-Jul	2.5	10.1	0.2	6.7	1.3
7-Jul	7.9	20.6	0.2	12.3	4.0
8-Jul	7.0	18.1	0.2	8.9	2.2
9-Jul	8.2	8.0	0.6	0.9	5.8
10-Jul	11.5	3.2	8.8	0.2	1.0
11-Jul	7.8	19.1	2.8	10.1	1.2
Totals	109.3	220.2	26.0	121.2	32.2

Solar Decathlon Project Comparison of 3 Cases:

1. No PV
2. PV with no storage
3. PV with storage



No Photovoltaics

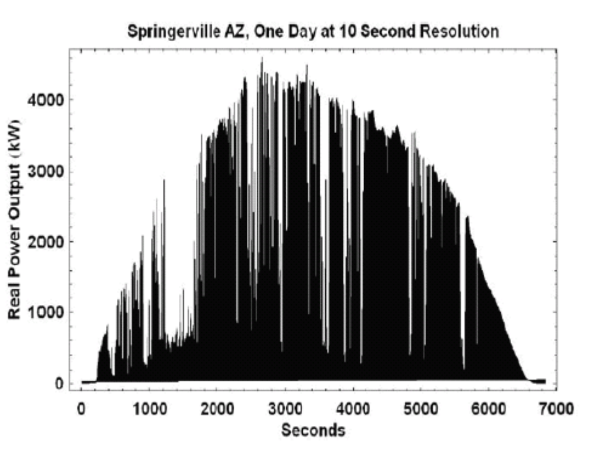
Photovoltaics but no storage

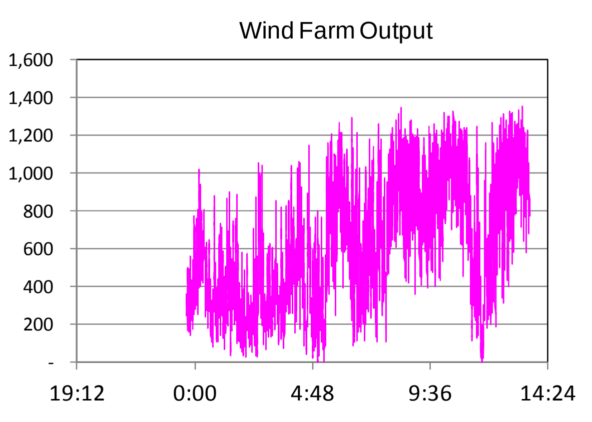
Photovoltaics with storage

Reasons for electrical storage

3. PV generation needs to be more constant due to variations during partly cloudy days

Solar and Wind Power is Typically Intermittent

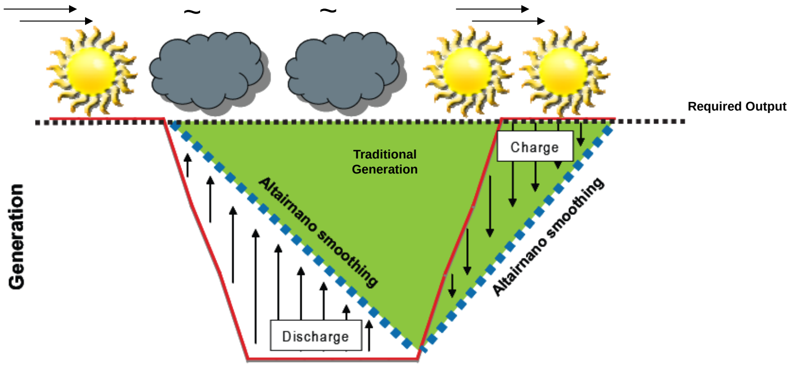




From Energy Storage Associates presentation

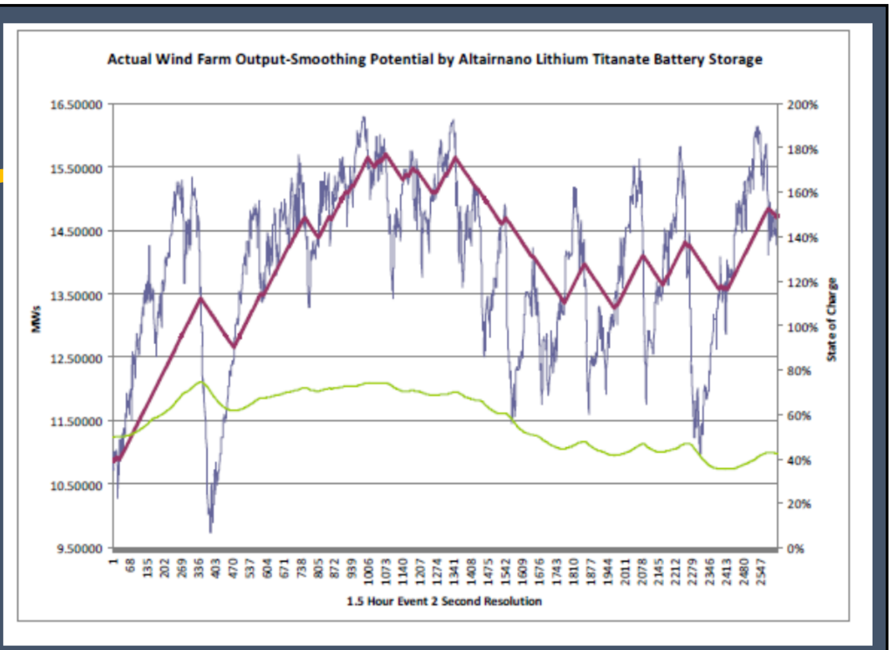
Renewable Energy Integration

Photovoltaic (PV) or Wind Power Smoothing



Energy Storage can smooth the abrupt changes of renewable generation to the acceptable limit the grid can handle.

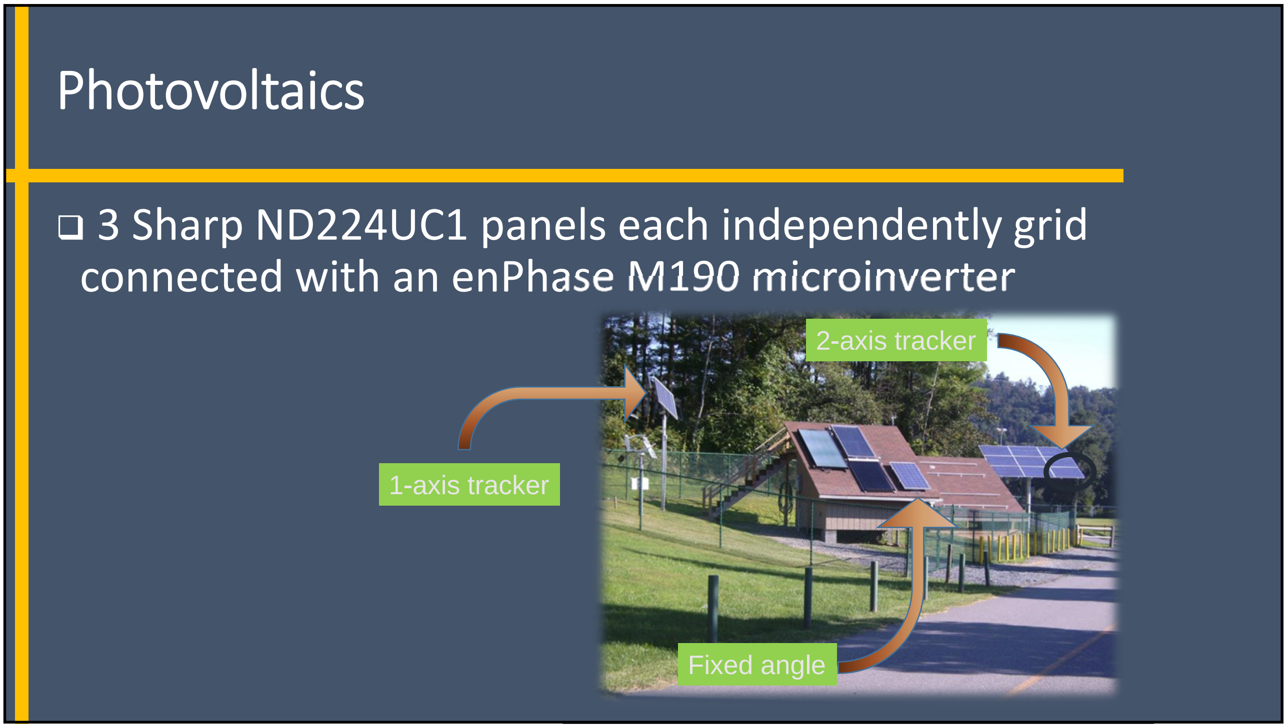
Wind Power Smoothing with Battery Storage


Actual Wind Farm Output-Smoothing Potential by Altairnano Lithium Titanate Battery Storage

- ❑ Source: www.altairnano.com

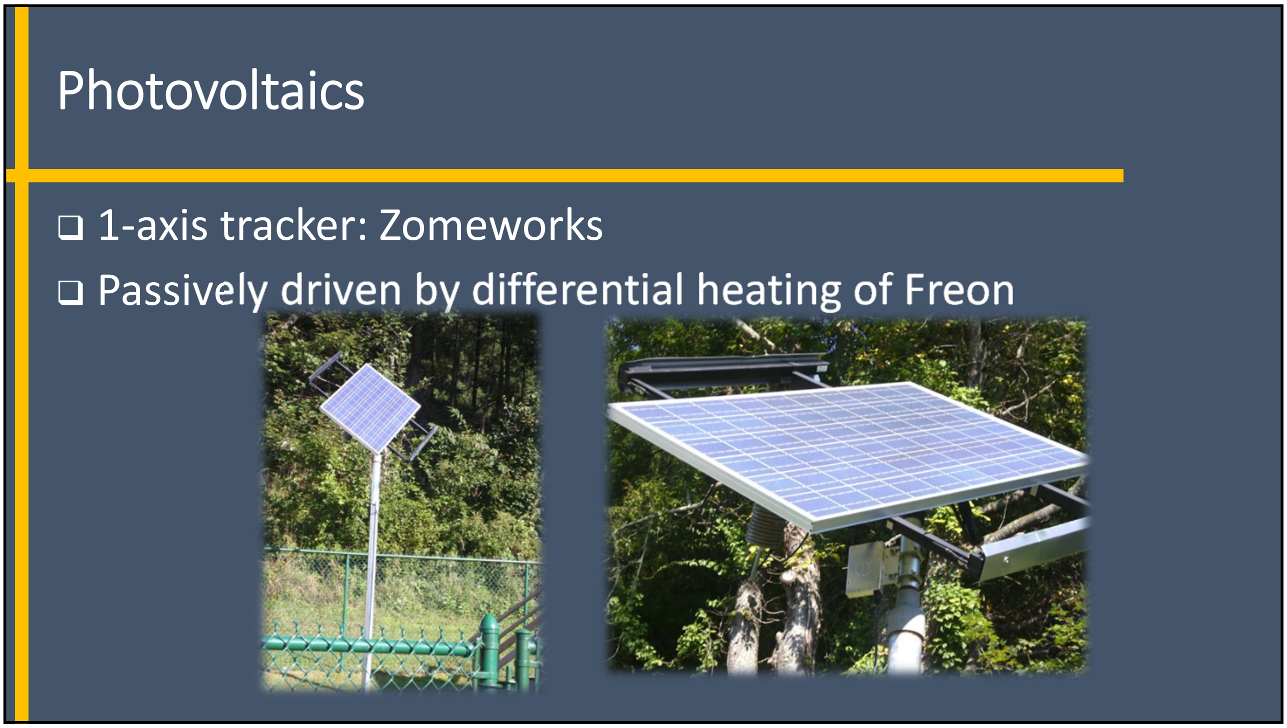
Solar Thermal Test Facility – One-Minute Data

- ❑ Appalachian State University Solar Research and Education Labs



Photovoltaics

- ❑ 3 Sharp ND224UC1 panels each independently grid connected with an enPhase M190 microinverter



Photovoltaics

- ❑ 1-axis tracker: Zomeworks
- ❑ Passively driven by differential heating of Freon

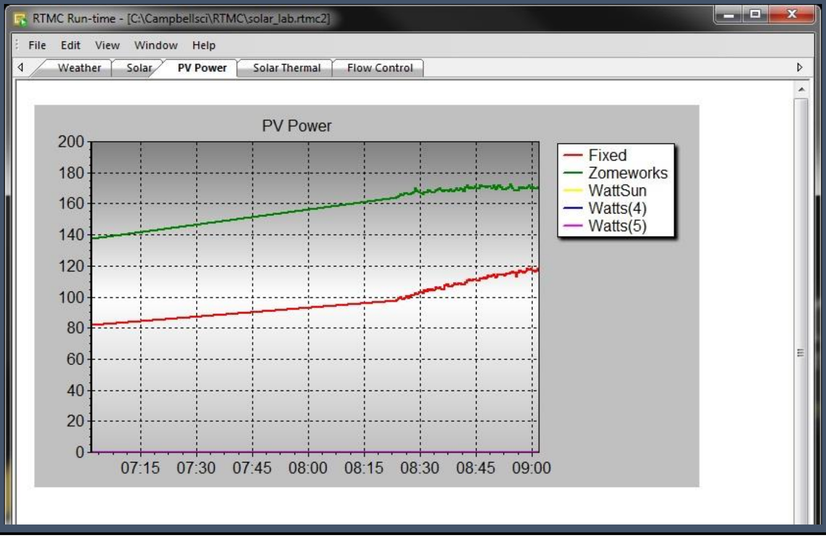
Photovoltaics

- 2-axis tracker: Wattsun
  - *Driven by active controls and electric motors*

Photovoltaics

- enPhase 190 W micro-inverter

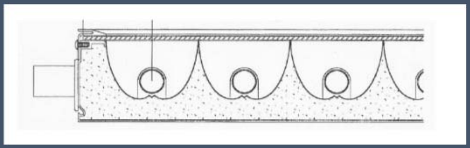
Photovoltaics – Monitoring System



Solar Thermal

Solar Thermal

- Three solar thermal collectors with very different geometries
  - Flat Plate (Alternate Energy Technologies)
  - Compound Parabolic Concentrator (Solargenix)



  - Heat Pipe Tube (Solar Collectors Inc)
- All mounted at fixed angle on the roof

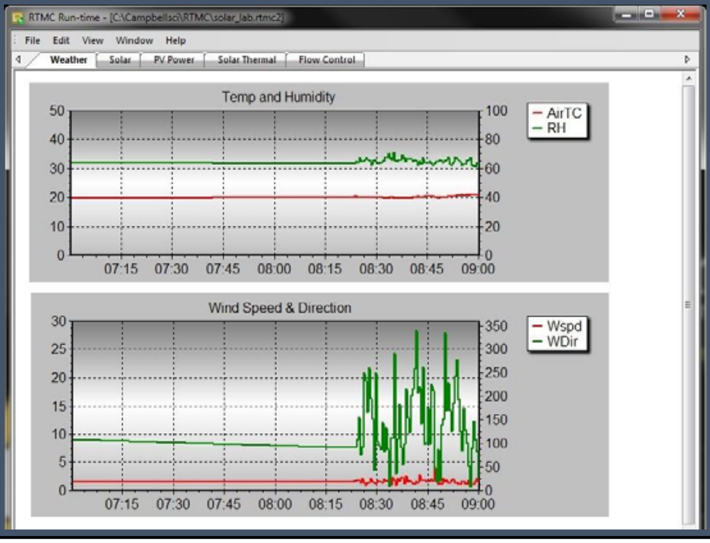
Data Collection

- Campbell Scientific
- CR1000 logger
- LoggerNet software

Meteorological instrumentation

- ❑ Ambient Temperature and Humidity
- ❑ Wind Speed and Direction
- ❑ Tipping Rain Bucket

Meteorological instrumentation

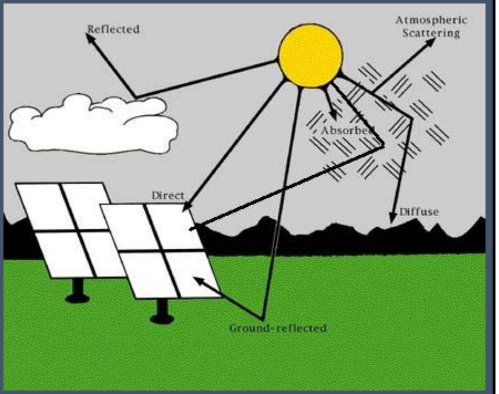


Solar Radiation instrumentation

❑ Direct Beam Radiation (DNI)

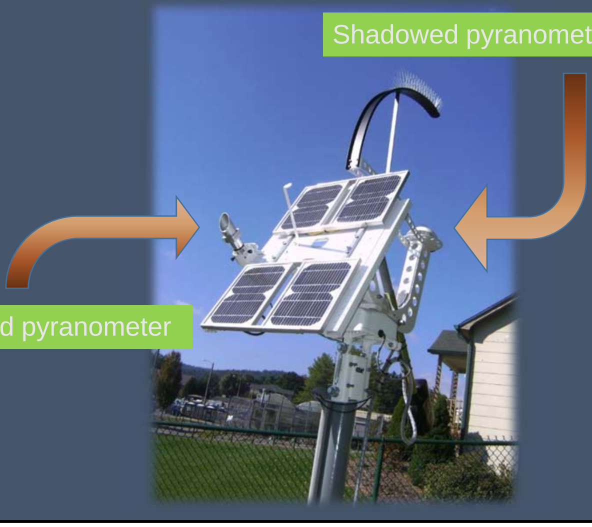
❑ Global Diffuse Radiation (GDIFF)

❑ Plane of Aperture Radiation (POA)



Direct beam Radiation

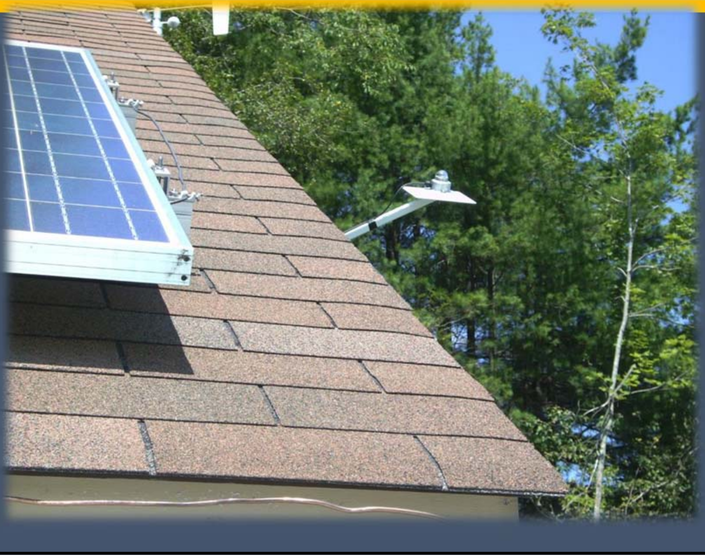
❑Pyrheliometer:
research grade tracker that points a collimated pyranometer at the sun



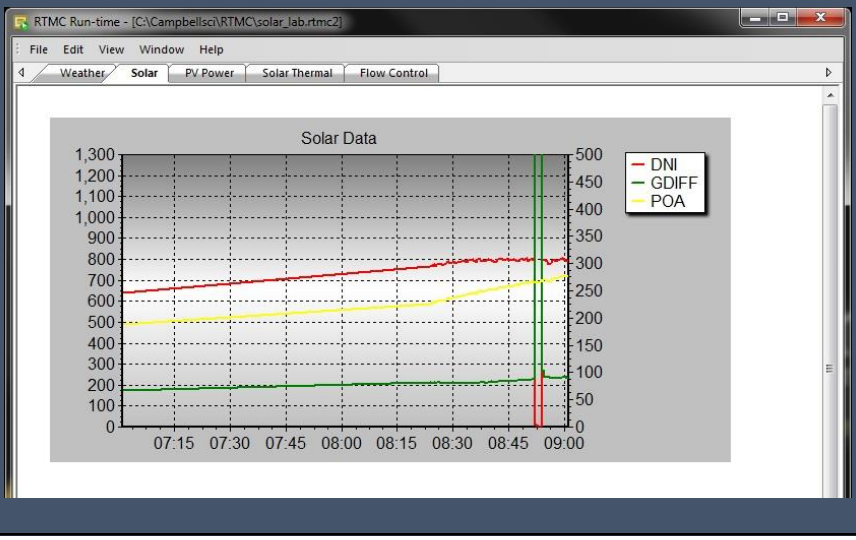
Shadowed pyranometer

Collimated pyranometer

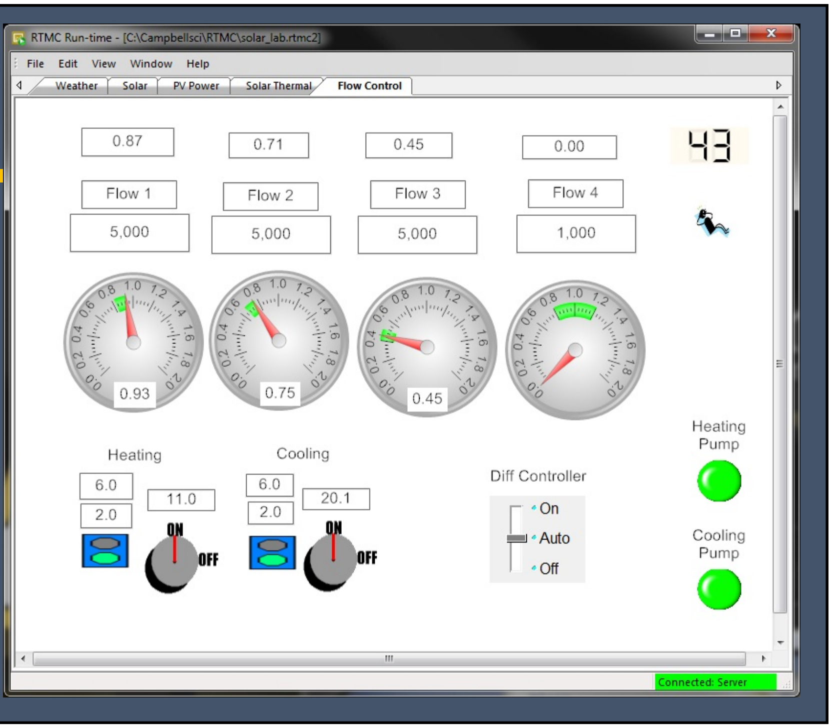
Plane of Aperture Radiation



Solar Radiation instrumentation



Solar Thermal



Flow 1: 0.87, 5,000, 0.93

Flow 2: 0.71, 5,000, 0.75

Flow 3: 0.45, 5,000, 0.45

Flow 4: 0.00, 1,000

Heating: 6.0, 2.0, 11.0

Cooling: 6.0, 2.0, 20.1

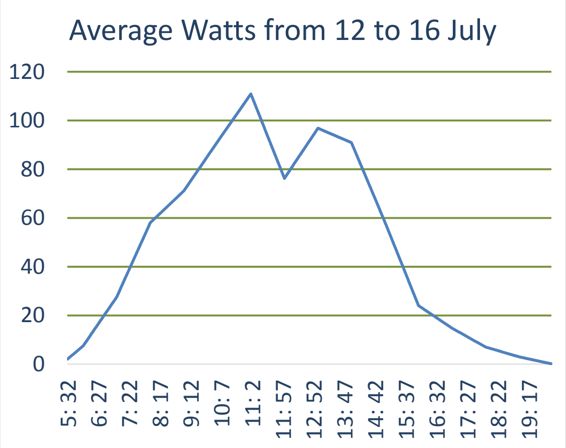
Diff Controller: ○ On ● Auto ○ Off

Heating Pump

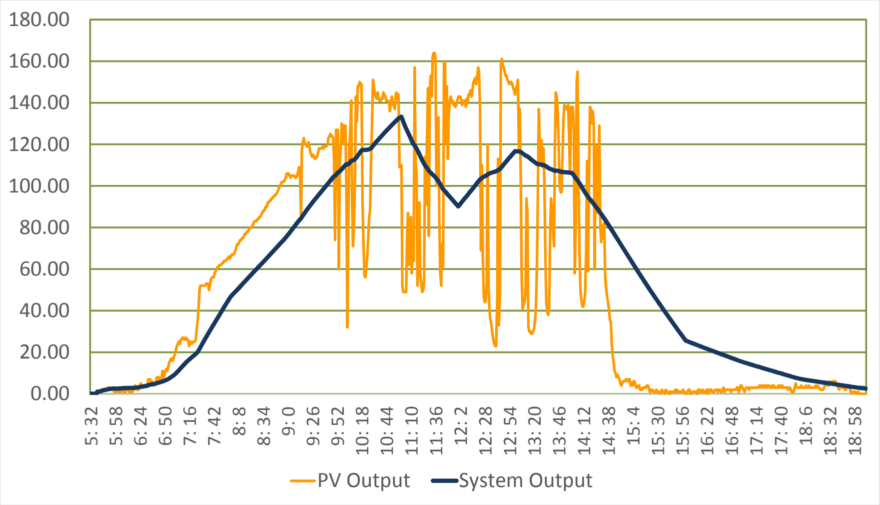
Cooling Pump

PV – Integrated Storage System Strategies

- ❑ Since levels of insolation are difficult to predict, improved weather models are needed
- ❑ We developed a curve for each day using the average sunlight per hour for the previous 5 days
- ❑ The values on this curve formed the basis for targeting PV output to the grid and to battery storage
- ❑ As each day progressed, the PV output was corrected based on how insolation levels matched the averages



Example of Generation Leveling with Battery Storage



PV Plant should function as a conventional power plant

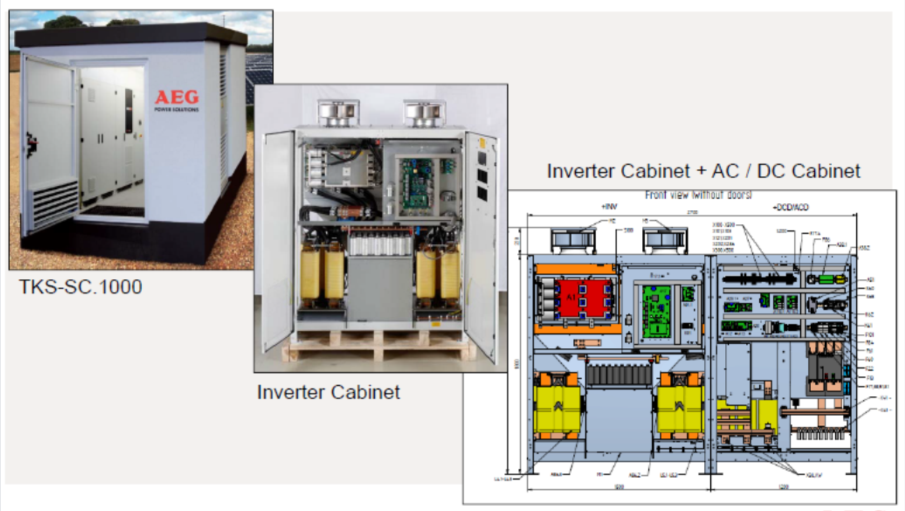
- **DSO / TSO desires / requires conventional power plant properties**
  - **LV fault ride through capability** √
  - **Fault current capability** ⇨ **Can be improved by EES**
  - **Participation in primary control (provision of positive and negative active power)** ⇨ **Requires EES**
  - **Provision of positive or negative reactive power** √ ⇨ **Can be improved by EES**

⇨ **Strong Demand for a Short Term Electrical Energy Storage System**

AEG
POWER SOLUTIONS

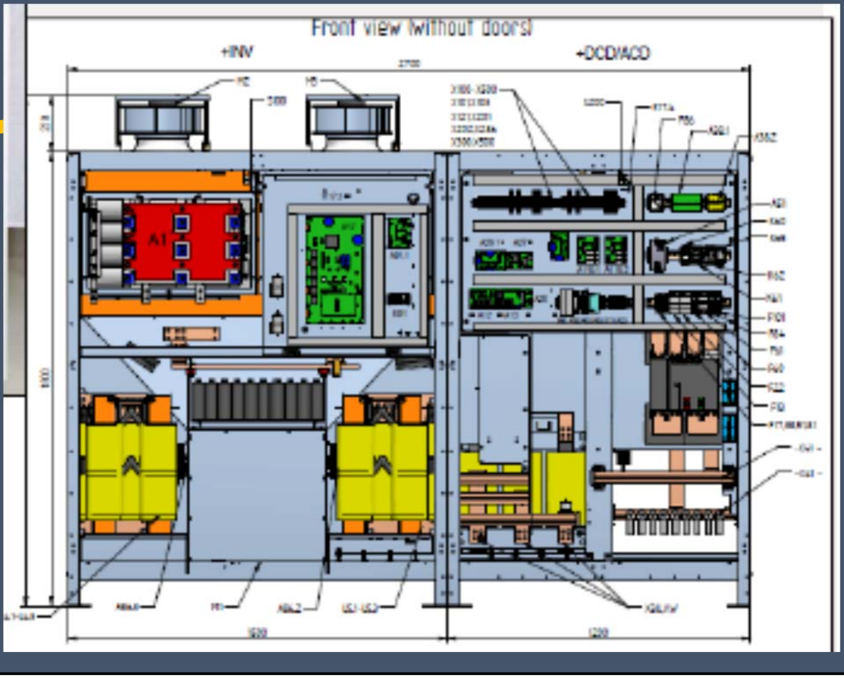
❑ Credit to AEG

AEG Layout of Building Energy Storage System



Prototype Layout of AEG Storage System

Inverter and AC/DC Cabinet



Protype Layout of Battery Container

Battery Container (Example)

Positioning and Connection of Batteries

Battery Container (Example)

Sample of Solar/Storage projects under way in the U.S.

- Duke Energy - Rankin Substation
  - Sodium Nickel Chloride for PV smoothing
- Duke Energy – Marshall Substation
  - Lithium Ion for Peak Shaving
- Chevron Santa Rita Jail Micro grid project
  - Lithium Ion for PV smoothing and Load shifting
- San Diego Gas and Electric
  - Lithium Ion for PV Smoothing
- PNM ARRA Funded Solar Smoothing and Load Shift
  - Advanced lead acid batteries

From: Brad Roberts presentation, Electricity Storage Association, SunSpec Alliance Member's Summit 2013, Las Vegas, NV.

Public Service of New Mexico
ARRA Project for Solar Integration with Storage

From: Brad Roberts presentation, Electricity Storage Association, SunSpec Alliance Member's Summit 2013, Las Vegas, NV.

PNM Project to Demonstrate Smoothing and Load Shifting of Solar Energy

- ❑ Project utilizes two advanced lead-acid technologies from East Penn Manufacturing
- ❑ Advanced lead acid for load shifting the solar peak to allow for dispatching at the highest load peak
- ❑ UltraBattery for smoothing of the solar output to demonstrate the high cycling capability of the technology
- ❑ Battery Ratings:
  - Advanced Lead Acid…..250 kW for 4 hours
  - UltraBattery…………….500 kW for 30 minutes

From: Brad Roberts presentation, Electricity Storage Association, SunSpec Alliance Member's Summit 2013, Las Vegas, NV.

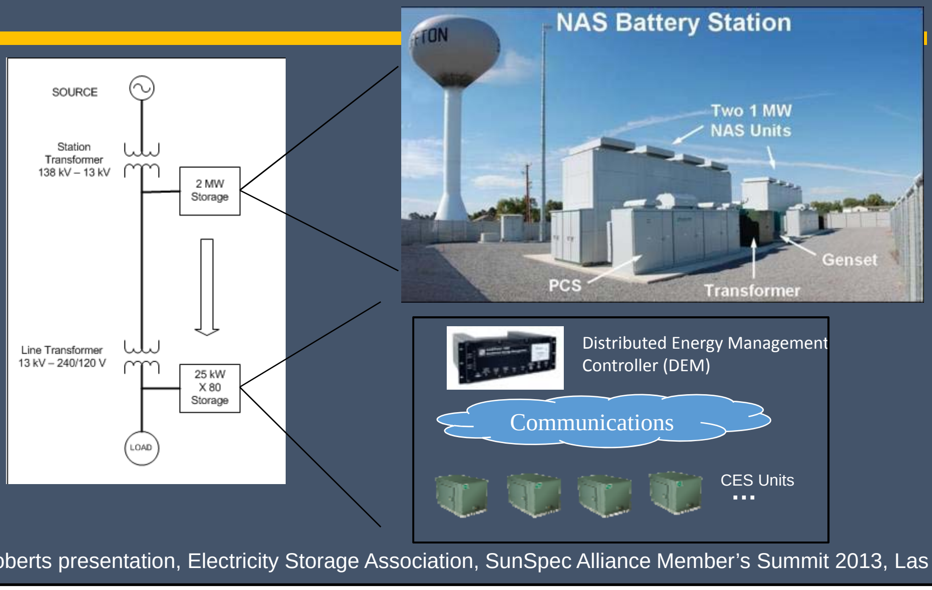
Kansas Hybrid Wind Solar & Storage Project Overview

Use the SPP methodology to establish average capacity credit for the summer months:

- ❑ A stand-alone solar facility yields 50% more capacity than wind
- ❑ A hybrid facility yields 80% more capacity credit than one wind and one solar stand-alone facility
- ❑ A hybrid facility with 6 hours of storage yields 160% more capacity credit than the stand-alone wind and solar facilities
- Values based on a hybrid facility of 100 MWs of wind, 20 MWs of solar and 15 MWs of storage for 6 hours. These are the optimum values for maximum benefit

From: Brad Roberts presentation, Electricity Storage Association, SunSpec Alliance Member's Summit 2013, Las Vegas, NV.

CES – Community Energy Storage

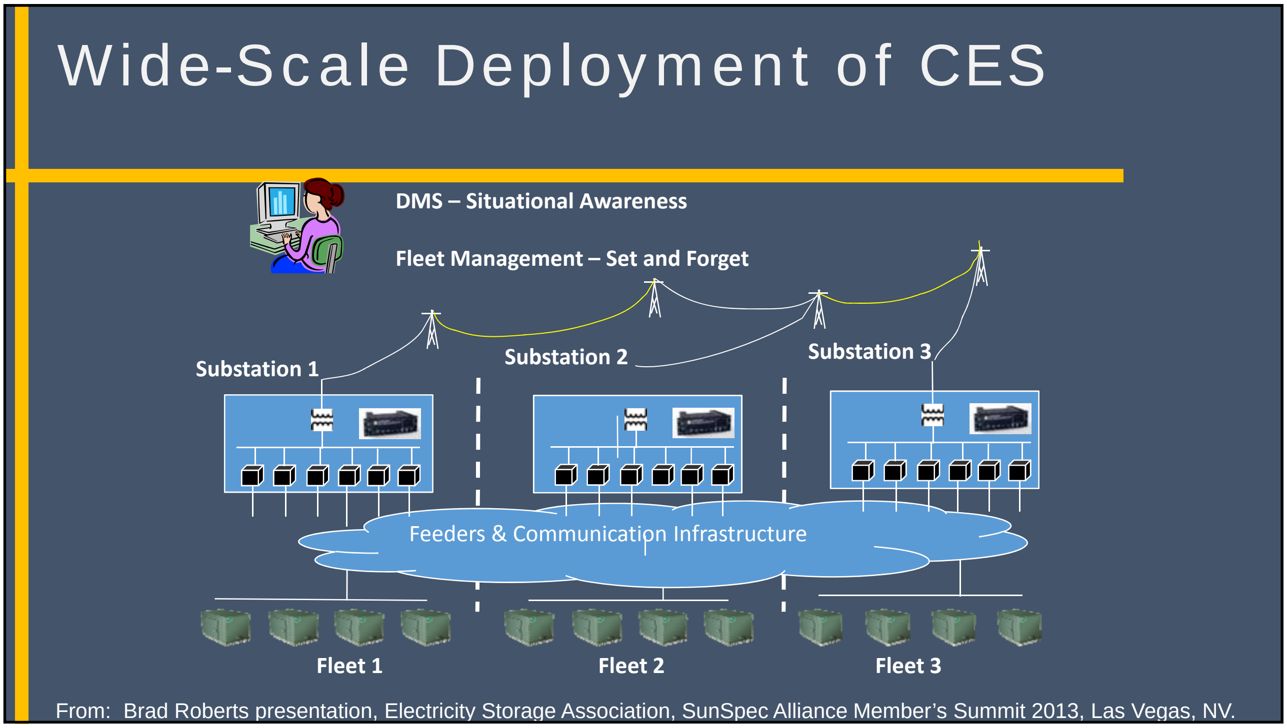


From: Brad Roberts presentation, Electricity Storage Association, SunSpec Alliance Member's Summit 2013, Las Vegas, NV.

Typical CES Installation

(AEG Presentation)

From: Brad Roberts presentation, Electricity Storage Association, SunSpec Alliance Member's Summit 2013, Las Vegas, NV.



Wide-Scale Deployment of CES

DMS – Situational Awareness

Fleet Management – Set and Forget

Substation 1

Substation 2

Substation 3

Feeders & Communication Infrastructure

Fleet 1

Fleet 2

Fleet 3

From: Brad Roberts presentation, Electricity Storage Association, SunSpec Alliance Member's Summit 2013, Las Vegas, NV.

Questions?