

Brookhaven National Laboratory Solar Energy and Smarter Grid Research Update

Presented to BNL CAC

Pat Looney

Chairman

Sustainable Energy Technologies Department

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Contributions from:

GARS: Bob Lofaro, Alessandra Colli, Stephanie Hamilton, Michael Villaran, Shawn Wang, Rangy Weidner, Meng Yue

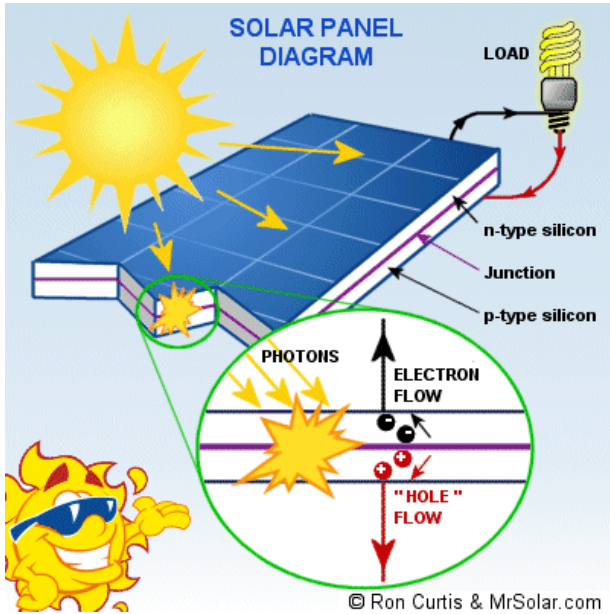
ELS: Paul Kalb, Dantong Yu, Shinjae Yoo, Scott Smith, John Heiser, Andrew Vogelmann, Michael Jensen

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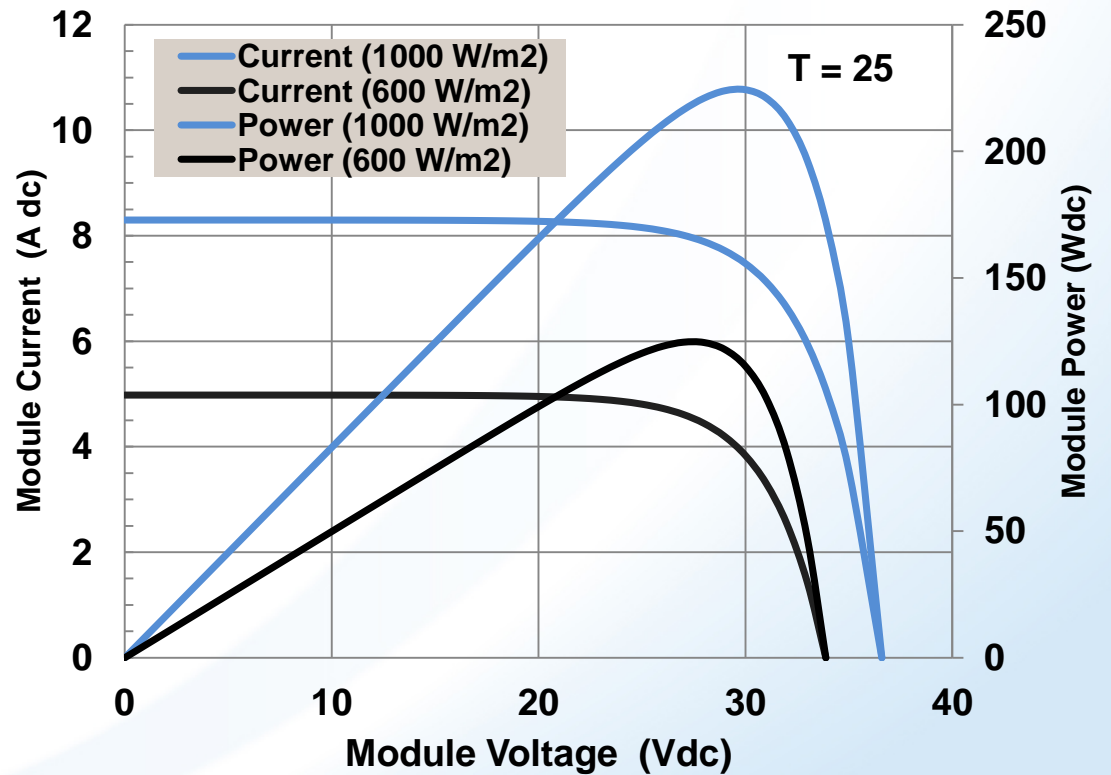
a passion for discovery



Quick Introduction to Solar Power



Calculated I-V Curves for BP 3225T Modules



Solar Research Focuses on Market Barriers



Design: 164,312 Si Mods./25 Inverters @ 1.25MW/27° Fixed Tilt

Reliability: 80% @ 25 Yrs (0.8%/yr)

Power: 32 MWe/44 GWh annually

Land: 200 acres/20 Year Easement

Utility Cost, Contract: 20 Year PPA/ Total \$298M/~\$0.30 kW

Financing: METLife

Permitting, Construction: Three Years from Proposal to Completion

Solar Research Focuses on Market Barriers

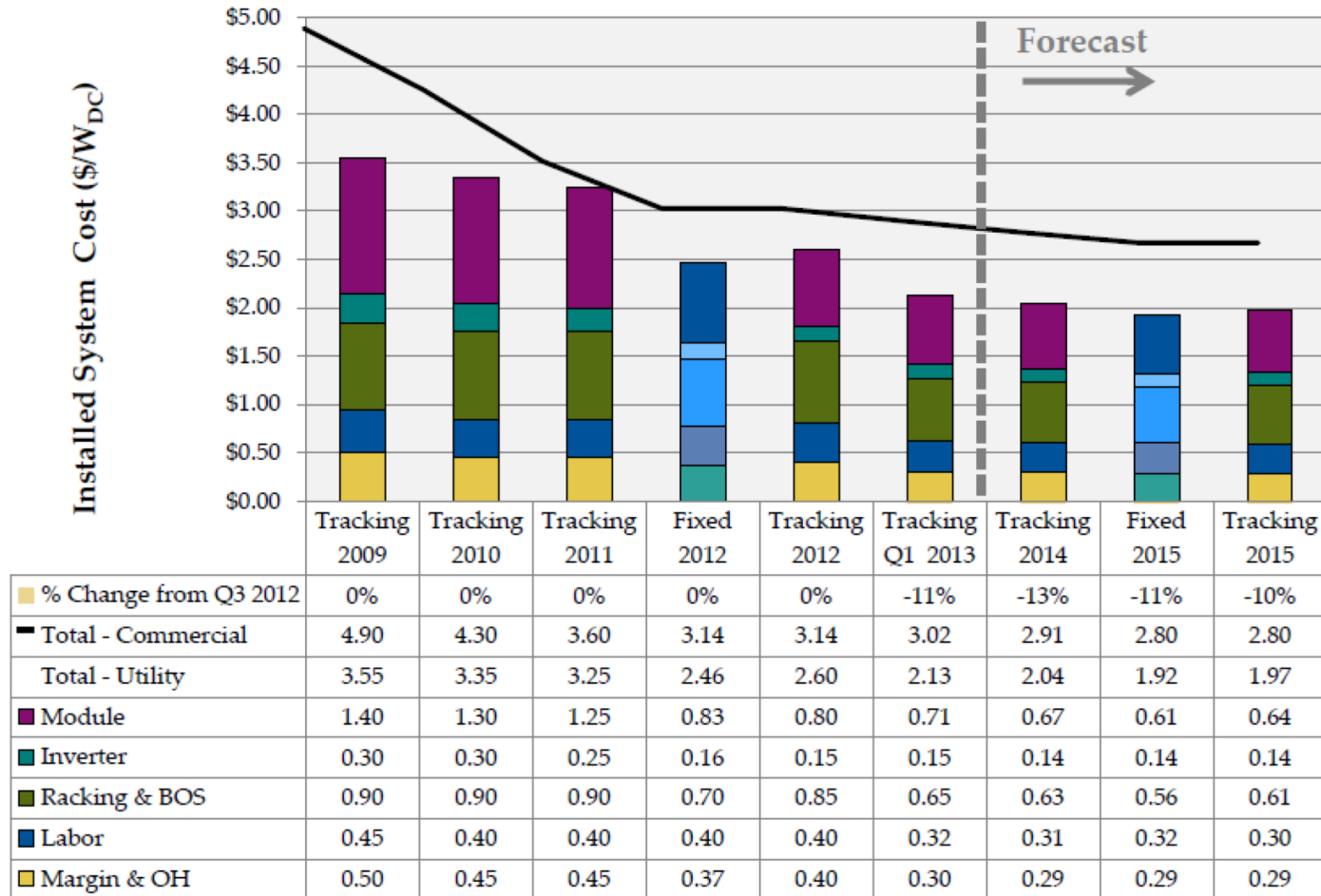


Figure 5: US Utility Scale PV System Prices - Tracking and Fixed Tilt, 2009-2015

Sources: Navigant estimate based on industry interviews, market reports, and primary market research Dec. 2011 – March 2013.

Notes: Utility scale plant sizes are estimated to be >10MW; Commercial scale plants are estimated to be >250 kW; Fixed tilt systems refer only to thin-film technology; Tracking systems refer to c-Si 1-axis tracking systems; Margin & Overhead include interconnection, permitting, and development costs among others; Racking & BOS costs include the racking, foundations, tracking hardware (if needed), wiring, roads, and security among others.

BNL's research agenda for solar energy and smarter electric grid focuses on two key areas

- Advancement of Solar Energy Generation in Northeast
 - Characterization of renewable generation
 - Impact of renewables on the grid
 - Role of storage to enhance benefits/mitigate the impacts of renewable
 - New technologies, such as advanced inverter controls, improve grid control

- Smarter Electric Grid Development
 - Advanced simulation of distribution networks and systems (e.g. graph trace analysis using iterators)
 - Modeling & advanced sensors to inform decisions on grid operation, validate/improve simulations
 - Evaluation of new technologies and control strategies for improved efficiency and reliability
 - Automated demand response, particularly in high density urban applications
 - Micro-grid concepts for improved reliance, resiliency

A key motivation for pursuing solar energy research at BNL is access to the Long Island Solar Farm ...

- **32 MWac grid-connected solar photovoltaic plant being built at BNL**
 - Owned by Long Island Solar Farm, LLC (company partially owned by BP Solar)
 - Purpose is to sell power to LIPA under a PPA
 - Commercial operation initiated Nov. 1, 2011
- **Located on 195 acres on BNL campus under an easement from DOE**
 - Consideration (in-kind funds) provided to DOE
 - BNL can instrument and collect data from the array for research purposes
- **BNL installed research instruments to collect data for research**
 - High-resolution, time synchronized data sets



LISF is complete and is generating power!

Commercial operation
November 1, 2011

BNL installed research instruments in the LISF

Collecting Time Synchronized, High Resolution (1sec.) Data Sets

■ Solar Resource Data

- Field Instruments: pyranometers 32 pairs @ 25 locations to measure direct and diffuse irradiance
- Base Station Instruments: Solar tracker, rotating shadowband radiometer for precision measurements



Rotating Shadowband Radiometer



Field Pyranometer

■ Meteorological Data

- Two Met Towers (85m & 10m)
 - Air Temp/Barometric Pressure
 - Wind speed and direction
- Array Field Instruments
 - Temperature (air, panel, soil)
 - Relative Humidity
- Total Sky Imagers – Cloud images



Power Quality Monitor



Pyrheliometer



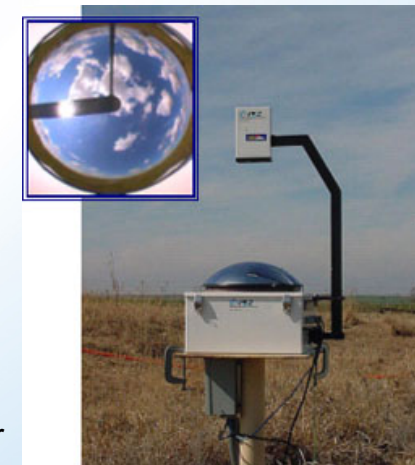
Pyrgometer

■ Electrical Performance Data

- Power Quality: all inverters, collection substation
- Power Quality: Utility feeders to BNL
- String Level: DC currents and voltages



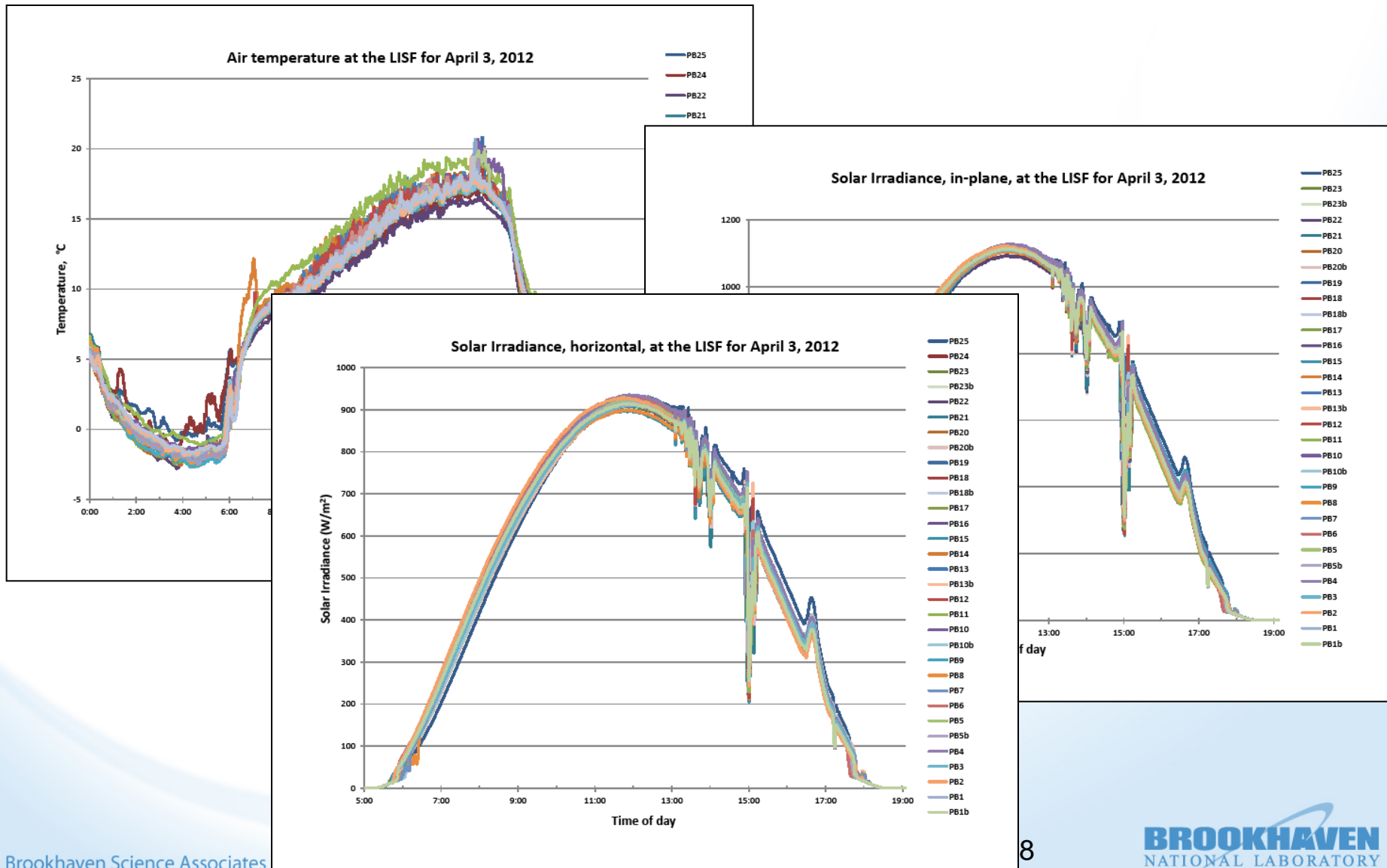
Sun tracker with sensors for global, diffuse and direct irradiance.



Total Sky Imager

BNL is collecting and storing LISF data

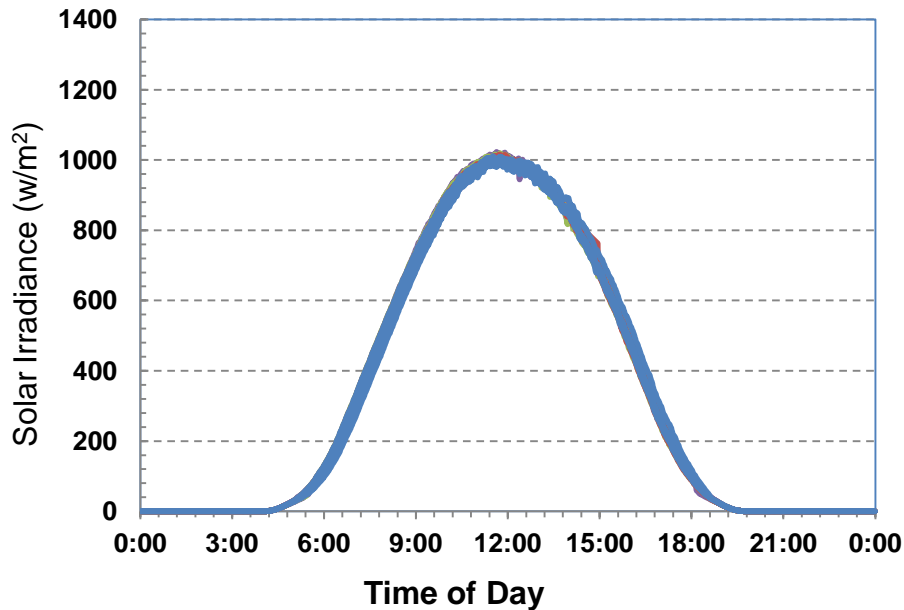
Data will be made available for research purposes



Solar Irradiance Comparison for Sunny vs. Cloudy Day

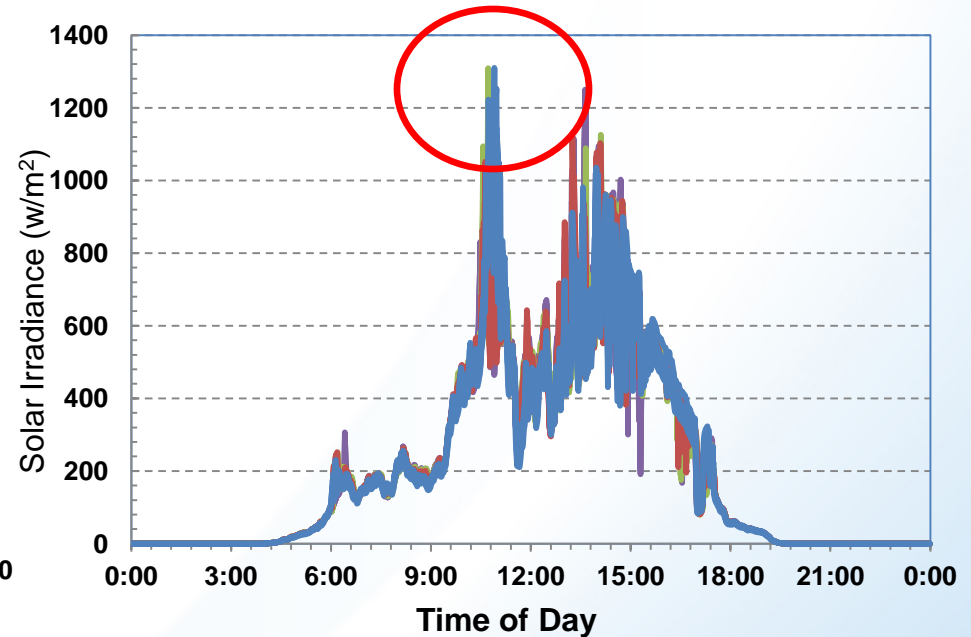
(Pyranometer data from 25 LISF power blocks)

In-plane solar irradiance – sunny day



Irradiance on sunny day peaks at approx. 1000W/m²

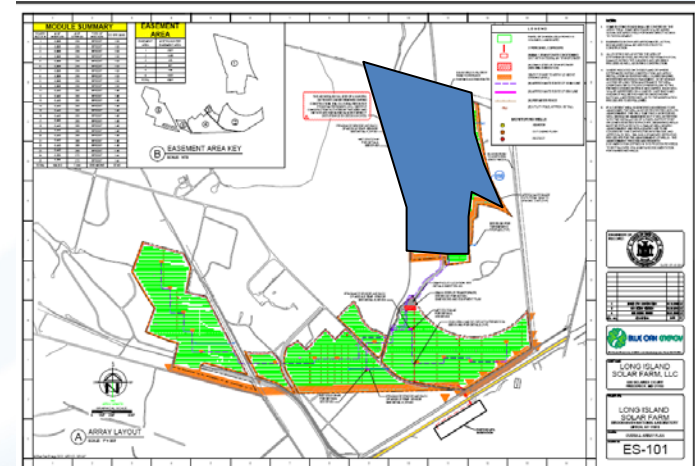
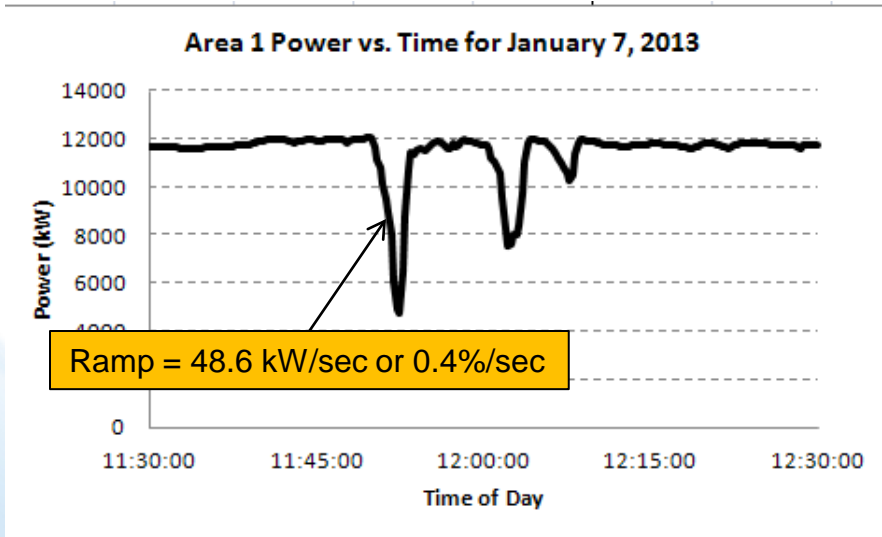
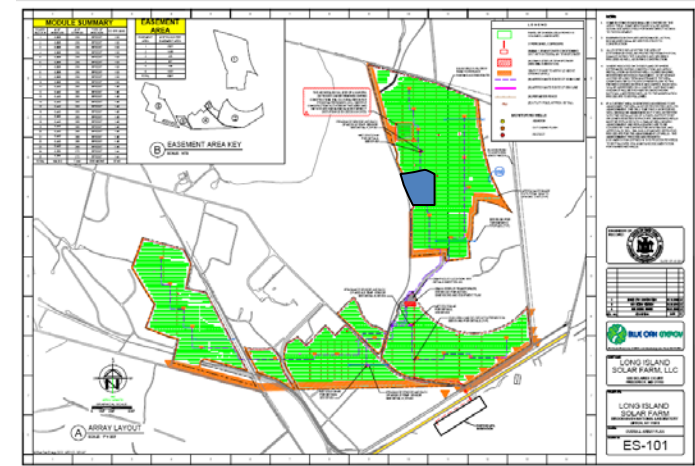
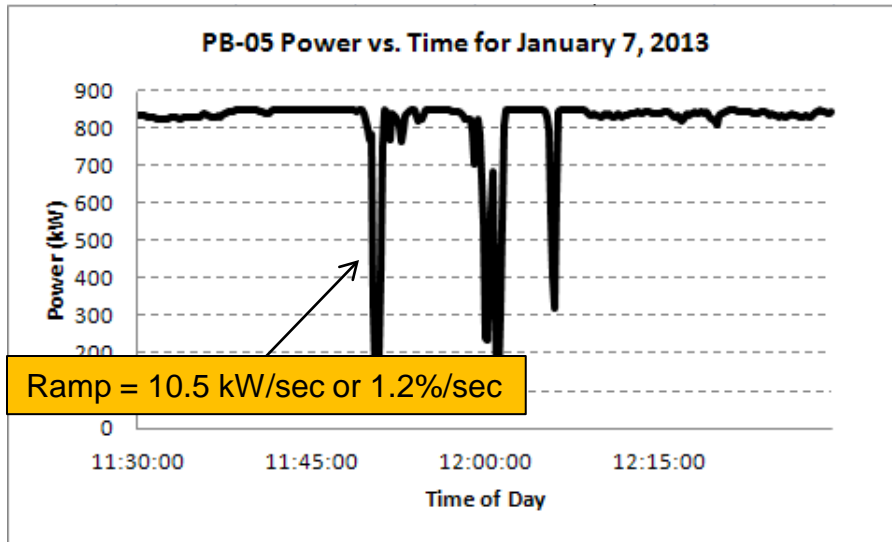
In-plane solar irradiance – cloudy day



Local irradiance on cloudy day can be higher due to reflection from clouds

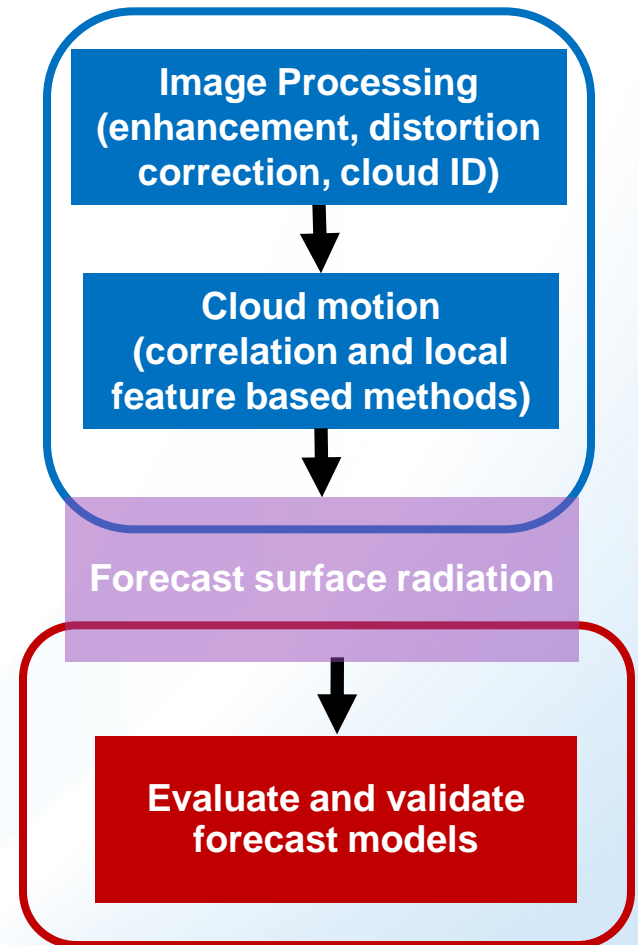
Power Output and Ramps During Cloud Transients

(Power data from 1 power block and total for Area 1)



Forecasting Research Agenda

- Develop tools for real-time processing of TSI images;
- Estimate cloud motion vectors based on sequential TSI images;
- Develop empirical/physical/hybrid models for radiation forecast;
- Test and validate the forecast system using LISF data;
- Interface cloud/radiation data for assimilation into VDRAS and WRF-Solar.



TSI image processing provides info about cloud location, size, and brightness.

- RGB and contrast enhancement

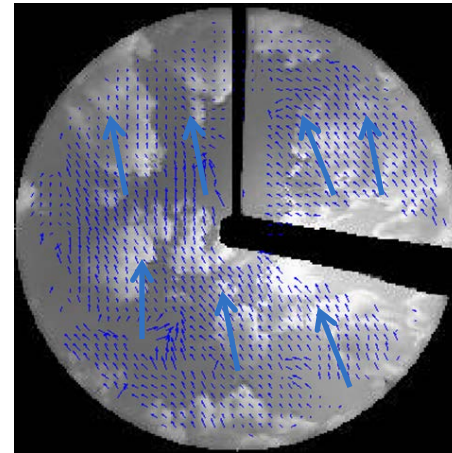
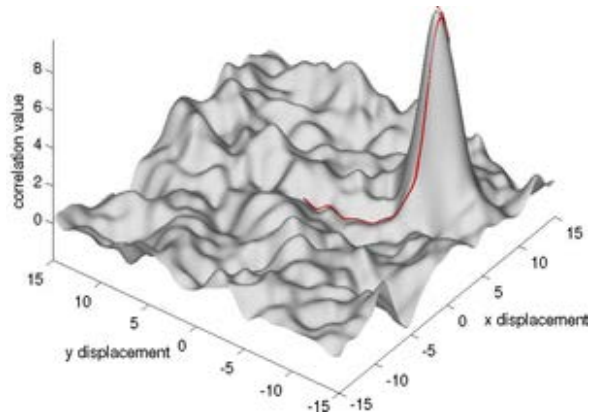


- Distortion correction

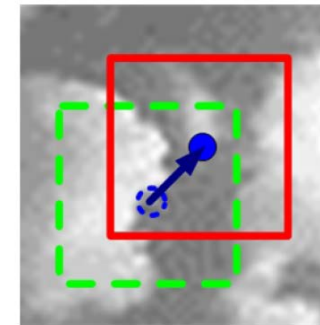
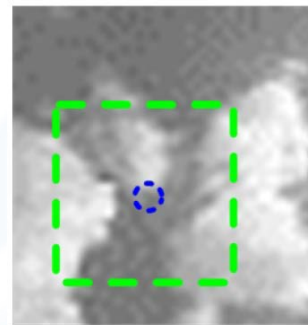
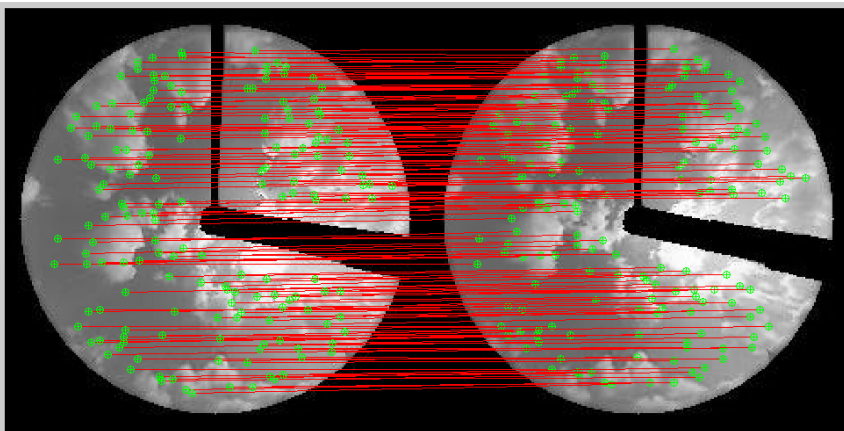


Cloud motion estimation

- Cross-correlation based approaches

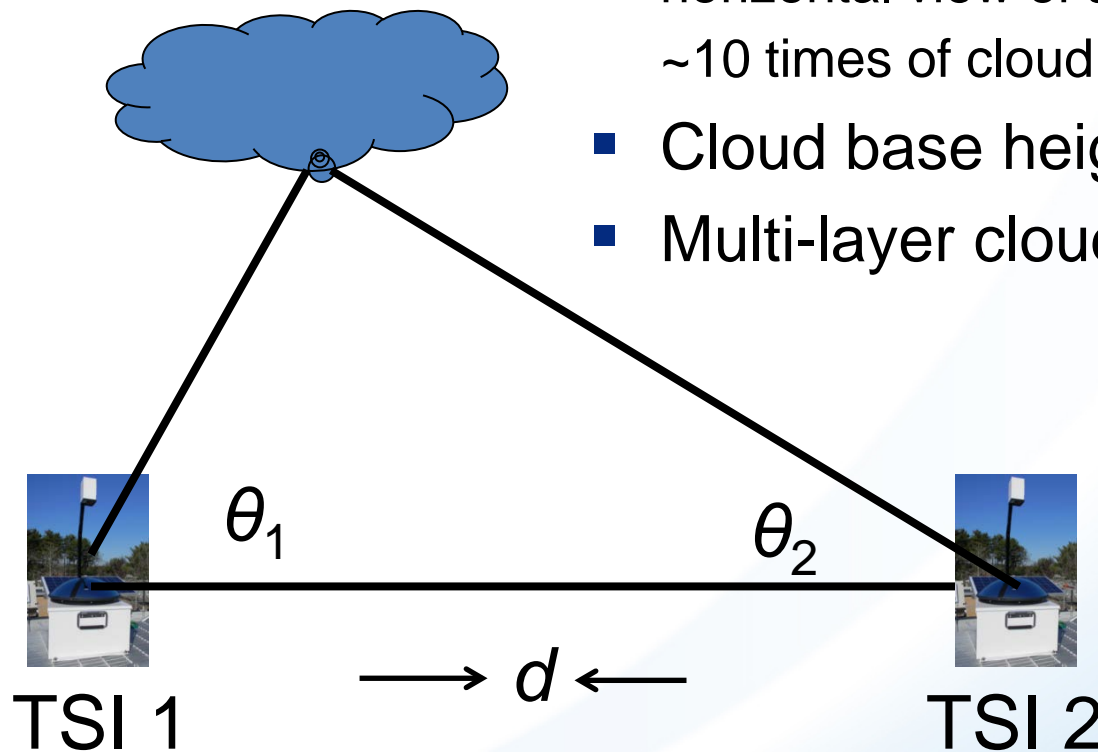


- Local feature based approaches



A network of TSIs can provide more information about clouds.

- Larger field of view (max horizontal view of a single TSI is ~10 times of cloud base height)
- Cloud base height
- Multi-layer clouds



LISF data enables research on issues that will foster the deployment of utility-scale solar PV systems

■ Solar Variability and Grid Integration

- Characterize solar variability for plants in the northeast
- Impact of solar variability on grid management for different penetration levels
- Impact of distributed generation on feeder performance (power quality, reliability)
- The role of storage to mitigate variability impacts
- The role of smart grid inverters providing ancillary services (DVAR, voltage regulation)

■ Forecasting

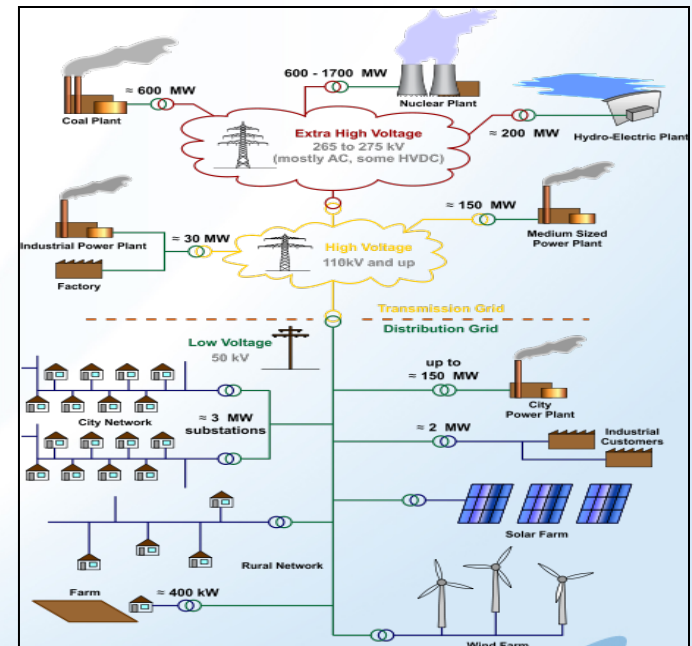
- Min/Hour/Day ahead solar resource forecasts
- Leverage BNL core capability in cloud physics and access to NOAA facility on site

■ Capacity Credit

- Develop and validate algorithms

■ Environmental Sustainability

- Impact of utility-scale solar PV plants on local environment and ecology
- Life cycle cost, recycling



BNL is also developing the Northeast Solar Energy Research Center (NSERC)

- Supplements LISF research
 - DOE owned facility on BNL campus
 - Available to support industry needs
- Comprised of two elements
 - Research array for field testing
 - Laboratories for standardized testing
- Resource for the Northeast
 - Field testing under actual northeast conditions
 - Technology development test bed
- Solar array connected to BNL electrical system
 - Help with BNL sustainability goals
 - Enable micro-grid test bed

NSERC Research Facility

- ✓ **Field Testing***
- ✓ **Grid Integration**
- ✓ **Solar PV**
- ✓ **Smart Grid Test Bed**
- ✓ **Energy Storage**
- ✓ **Smart Grid Inverters**
- ✓ **Solar Forecasting**
- ✓ **Reliability & Degradation**
- ✓ **Environmental Sustainability**

Development of the array is underway...

- Site selected for the research array
 - BNL main campus ~6.9 acres
 - Land prep is completed
- Architect-Engineering firm hired
 - Blue Oak Energy (designed LISF)
- Final design complete
 - Received January 24, 2013
- Long-lead equipment ordered
 - Solar Modules for Area 1
 - Inverters for Area 1
 - Racks for Area 1
 - Transformer for connection to BNL
- Construction contract out for bid
 - Bids expected Feb 22
- SCADA contract out for proposal
 - Proposals expected Feb 4



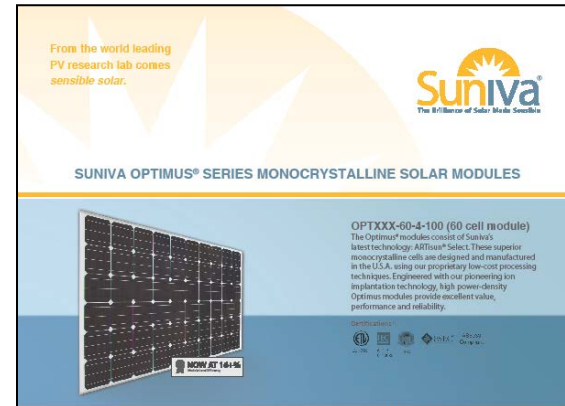
Final Design of the research array is complete

■ Nominal Specifications

- Power output: ~1MW-ac
- Reconfigurable architecture
 - 50kw – 350kw blocks
 - Voltage 600V/1000V
- Solar Modules – Suniva Crystalline silicon
 - ~16% efficiency
 - Buy American Compliant
- Racking: Northern States Metal
 - Fixed tilt (90%) /Single Axis trackers (10%)
- Inverters: Aurora Power One Modular
 - Capability for individual MPPT control of blocks

■ Test Capabilities

- Inverter testing from utility-scale to string level and micro inverters
- Storage systems – separate test pad provided
- Microgrid – ring bus architecture included
- Solar module testing – empty racks for module testing



From the world leading PV research lab comes sensible solar.

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SUNIVA OPTIMUS® SERIES MONOCRYSTALLINE SOLAR MODULES

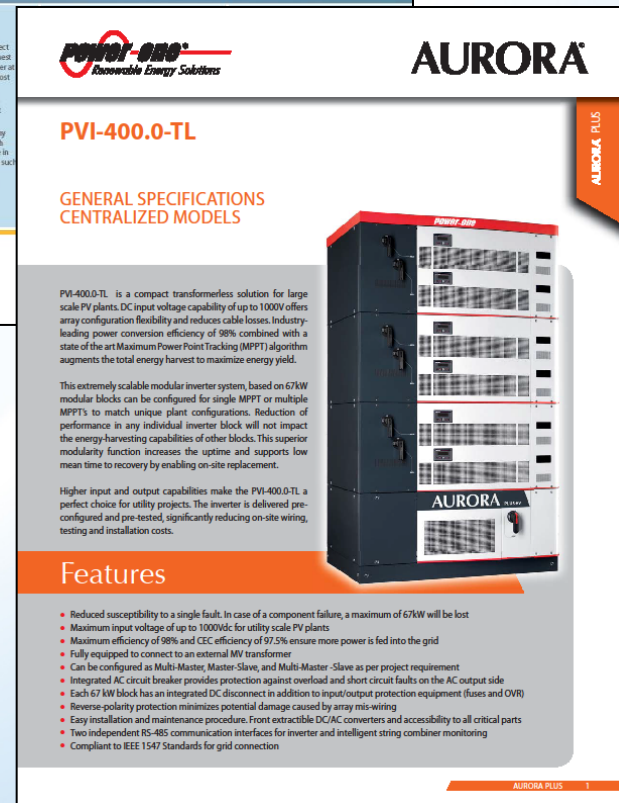
OPTXXX-60-4-100 (60 cell module)
The Optimus® modules consist of Suniva's latest technology, AllTissue® Select. These superior monocrystalline cells are designed and manufactured in the U.S.A. using our proprietary low-cost processing techniques. Engineered with our pioneering ion-implantation technology, high power-density Optimus modules provide excellent value, performance and reliability.

certifications: UL 1741, IEC 61215, IEC 61730, ISO 9001, ISO 14001

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Engineering Excellence

- Built exclusively with Suniva's highest-efficiency AllTissue Select cells, providing one of the highest power outputs per square meter at an affordable manufacturing cost
- Suniva's state-of-the-art manufacturing facility features the most advanced equipment and technology
- Suniva is a U.S.-based company spun out from the Georgia Tech University Center of Excellence in Photovoltaics, one of only two such research centers in the U.S.



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AURORA

PVI-400.0-TL

**GENERAL SPECIFICATIONS
CENTRALIZED MODELS**

PVI-400.0-TL is a compact transformerless solution for large scale PV plants. DC input voltage capability of up to 1000Vdc offers array configuration flexibility and reduces cable losses. Industry-leading power conversion efficiency of 98% combined with a state of the art Maximum Power Point Tracking (MPPT) algorithm augments the total energy harvest to maximize energy yield.

This extremely scalable modular inverter system, based on 67kW modular blocks can be configured for single MPPT or multiple MPPT's to match unique plant configurations. Reduction of performance in any individual inverter block will not impact the energy harvesting capabilities of other blocks. This superior modularity function increases the uptime and supports low mean time to recovery by enabling on-site replacement.

Higher input and output capabilities make the PVI-400.0-TL a perfect choice for utility projects. The inverter is delivered pre-configured and pre-tested, significantly reducing on-site wiring, testing and installation costs.

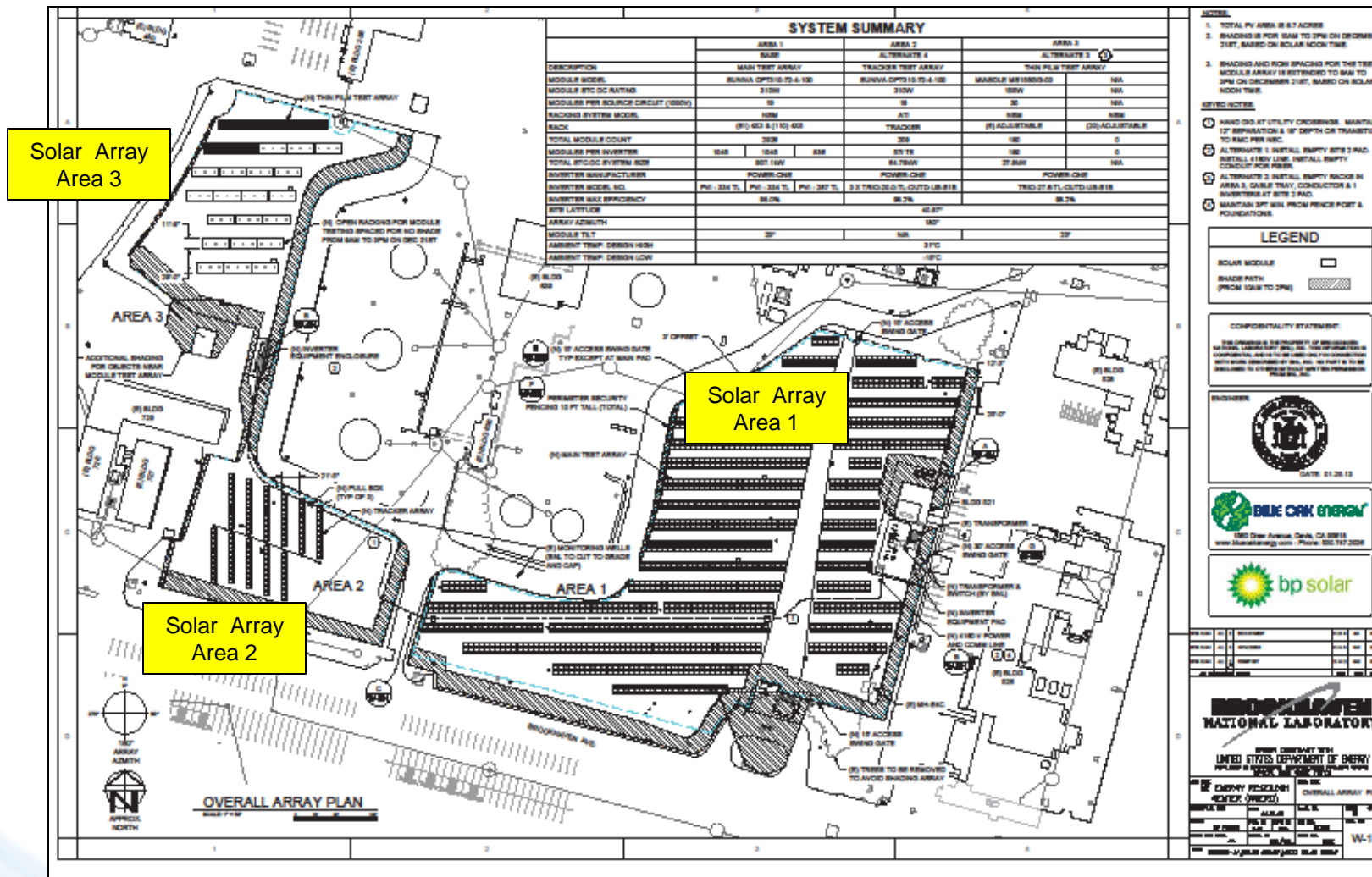
Features

- Reduced susceptibility to a single fault. In case of a component failure, a maximum of 67kW will be lost
- Maximum input voltage of up to 1000Vdc for utility scale PV plants
- Maximum efficiency of 98% and CEC efficiency of 97.5% ensure more power is fed into the grid
- Fully equipped to connect to an external MV transformer
- Can be configured as Multi-Master, Master-Slave, and Multi-Master-Slave as per project requirement
- Integrated AC circuit breaker provides protection against overload and short circuit faults on the AC output side
- Each 67 kW block has an integrated DC disconnect in addition to input/output protection equipment (fuses and OVR)
- Reverse-polarity protection minimizes potential damage caused by array mis-wiring
- Easy installation and maintenance procedure. Front extractable DC/AC converters and accessibility to all critical parts
- Two independent RS-485 communication interfaces for inverter and intelligent string combiner monitoring
- Compliant to IEEE 1547 Standards for grid connection

AURORA PLUS

AURORA

The design includes 3 separate test areas...



Area 1: ~907kw-dc for testing inverters, storage and micro-grids – and provide power to BNL
 Area 2: ~ 65kw-dc for testing modules on trackers
 Area 3: ~150kw-dc for testing new module designs and inverter topologies

BNL is installing smart sensors in the campus electrical network as part of the smarter grid research agenda

Smart Micro-Grid (SMG) Demonstration Project



- BNL has a 20 MW base load representative of a typical industrial complex; 13.8 kV primary distribution, peak load of ~70MW
- An active collaboration is in place for placing a network of new generation grid sensors in the BNL distribution system
- BNL will evaluate how advanced monitoring and modeling can be used to better manage distribution systems
- NSERC includes renewable generation on the BNL grid and will enable using the site as a microgrid test bed.

Thank you!