Grid Integration and Plant Control Systems for Utility-Scale PV Power Plants

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14 – 15 May 2013, Cape Town, South Africa
Pre-conference workshops: 13 May 2013 | Site visits: 16 May 2013
Key Messages

- PV power plant is a cost-effective energy resource
- Modern PV plants can contribute actively to grid stability and reliability
- PV variability can be managed without significant impact to existing grid infrastructure through forecasting and site diversity
First Solar - Utility Scale PV Plant Leader

Over 3.0 GW Completed or In Development (10MW_{ac} – 550 MW_{ac} Plants)

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Impact of Cloud Passage on Plant Output

As plants become larger... high frequency variability reduces.

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Effect of Plant Size

- Larger plants are less variable
- Cloud shadows effect only a portion of the plant
- Power deviations are less severe

As plants become larger... ramp rates are smaller.

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Aggregation Effect Between Plants Reduces Variability

- Multiple plants space out are less variable
- Effects of cloud shadows are isolated to single array fields
- Power deviations are less severe

Spatial diversity of solar plants reduces aggregated variability … minimizing grid impact as the number of solar plants increase
Aggregation Effect Between Plants Reduces Variability

Single Project vs. 8 Bundled Projects

August 28, 2010

PV 1 & 2: ~43% drop

PV 5: 59% drop

13% drop

11% drop
One-Minute Ramps for 5 and 80 MW Plants

Source: Empirical Assessment of Short-term Variability from Utility Scale Solar-PV Plants
Rob van Haaren\textsuperscript{a}, Mahesh Morjaria\textsuperscript{b} and Vasilis Fthenakis\textsuperscript{a}

As plants become larger… ramp rates are lower.
Grid Integration Topics
Variable Generation Integration Topics

- Grid Stability and Reliability
- Load Balancing
- Power Systems Planning and Design

Milliseconds to Minutes  →  Hours to Days  →  Years

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“Modern solar plants can now contribute to the reliability and efficiency of grid operation by offering the following capabilities:”

- Voltage, VAR control and/or power factor regulation
- Fault ride through
- Real power control, ramping, and curtailment
- Primary frequency regulation
- Frequency droop response
- Short circuit duty control
Typical Utility Scale PV Plant

PVCS (Photovoltaic Combining SWGR)

PCS (Power Conversion Station)
Inverters, Fuse Box and Step Up XFMRS

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First Solar offers the most advanced grid integration and plant control system in the PV industry, requiring no customer development.

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First Solar Plant Control System Architecture

- Monitor conditions at the POI and compare them with the Set Points
- Send commands to inverters to make output adjustments and achieve POI requirements

Grid Point of Inter-connection (POI)
Voltage Regulation

Voltage controller monitors POI and set point

Deviation detection triggers adjustment of inverter reactive power output

Inverters/Cap change output to restore voltage

Grid Monitor

Voltage Set Point

Voltage, Active and Reactive Power

Grid Voltage

Set Point

Operator

Substation RTU

Voltage Deviation

Plant Controller

Inverter 1

MV Transformer

Inverter 2

MV Transformer

Inverter N

MV Transformer

Power Grid

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Benefit of Central Control System

Without a central control system, all inverters are unnecessarily curtailed when plant output limit is reached... reduced captured energy.
Benefit of Central Control System

With a central control system, inverters are individually controlled to meet the plant limit, resulting in increased captured energy.
Dynamic Power Factor Regulation

Power Factor Set Point Changed from 0.98 to 1.0

Reaches 90% Steady State Value in ~ 3.2 seconds

Inverters Change VAr Output

Excellent Reactive Power Dynamic Control


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Plant Curtailment Test
Power Curtailment at Different Levels

Excellent Control over Active Power

Set Point Reduced

Inverters are Turned Down/ OFF to curtail output

Set Point Increased

Ramp rates between set point changes are controlled

Ramp Rate Controls
Stopping and Starting One Block (30MW)

Inverters are Turned Off in Sequence; Ramp Rates are Controlled

Inverters are Started in Sequence

Excellent Control over Active Power

Note that the plant is under construction, and only 1 block (30MW) out of 3 is under central control

Frequency Droop Control

• Ability to reduce active power in case grid is overloaded (i.e., high frequency)

✗ When grid needs more generation (i.e., low frequency) renewable plant cannot increase active power … unless plant is already curtailed then it can increase power

Plant Controls Support Frequency Droop

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PV Plants are designed to support both voltage and frequency ride-through capability leveraging utility scale inverters and best practices.
NRG/MidAmerican – Agua Caliente 290MW_{ac}

- Yuma County, Dateland, Arizona, USA
- 2,400 Acres
- 39,000 Tons Steel
- PPA: PG&E
- EPC/O&M: NRG

First 2008 EPC Project
Sempra – El Dorado 10MW

North America Largest PV Plant
Enbridge – Sarnia 80 MW
NextEra / GE – Desert Sunlight – 570MW_{ac}
Conclusions

- Modern PV plants can contribute actively to grid stability and reliability
- PV variability can be managed without significant impact to existing grid infrastructure through site diversity and forecasting
- PV power plants offer a cost-effective energy resource
- Lessons learned to date on Renewable Integration:
  - Large-scale PV has been successfully integrated into grids worldwide
  - No reported issues due to often cited barriers: PV variability, harmonics, DC current injection, anti-islanding failure or protection coordination
  - Bulk energy storage has not been necessary for variable generation integration