Sustainable Energy: Solar Power’s Transition into a Mainstream Generation Resource

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Enabling a world powered by reliable, affordable solar electricity.
Key Messages – Solar’s Transition into Mainstream Generation Source

• **Solar contributes < 1%** of total world electricity generation. But it has the potential to contribute **up to 25% of global electricity by 2050**

• Global PV Forecasted to Grow from **40GW in 2010 to ~700 GW by 2020**
  — Favorable value proposition: **clean, affordable, sustainable** energy
  — Solar electricity now **costs less** than thermal generation in several markets

• Challenges with Growth of Solar Energy (CPUC White Paper)
  — Maintain **grid stability and reliability** while integrating large-scale solar into electricity grid system
  — **Increase grid flexibility** to reduce solar curtailment

Solar Resource is Very Abundant ...

Annual World Energy Consumption ↑ 75%

Fossil Fuel Reserves (TWy)
- Coal: 900 TWy/yr
- Oil: 240 TWy/yr
- Natural Gas: 215 TWy/yr
- Uranium: 90-300 TWy/yr

Renewables per Year
- Hydro: 3-4 TWy/yr
- Wind: 25-70 TWy/yr
- Solar: 23,000 TWy/yr

“The sun will be the fuel of the future”
Anonymous, 1876, Popular Science

Global installed generating capacity and projected additions, by technology (GW)

- **2015**
  - Coal: 31%
  - Wind: 7%
  - Solar: 4%
  - Gas: 26%
  - Hydro: 5%
  - Nuclear: 18%
  - Other: 2%

- **2040**
  - Solar: 29%
  - Wind: 13%
  - Gas: 15%
  - Hydro: 4%
  - Nuclear: 4%
  - Coal: 16%
  - Other: 8%
  - Flexible: 4%

- **Outlook**: Global electricity market in 2040

- Solar becomes the least cost generation option in most markets


~3X Growth in Total Generation Capacity

~30X Growth in Solar Capacity
Solar PV is Growing Rapidly Globally ...from ~40GW in ‘10 to ~700GW in ‘20

Key Drivers:
- Environmental Benefits
- Public Policy on Renewables
- Rapidly Declining Costs

18 X Growth within a decade

310 GW by end of ‘16
Historically, module prices have decreased as a function of cumulative global shipments (blue dots reflect historical data, red dots reflect extrapolated prices for 1 TW and 8 TW based on the historical trend line). See supplementary materials for data sources.

“Terawatt-scale photovoltaics: Trajectories and challenges”, Haegel et al., Science Mag, 14 APRIL 2017, VOL 356 ISSUE 6334
PV Systems are Scalable, From Few kW .... Few Hundreds of MW

Cost of Energy Reduces with Scale
Utility-Scale Solar Energy is Competitive Today ... *Eliminates Fuel Price Volatility*

Source: Lazard Levelized Cost of Energy Analysis – Version 10;
Globally, Projects Are Growing and Prices are Falling

Global Tendered Solar Projects by Bid Price ($/MWh) and Capacity (MWdc)

Source: GTM Research

Kann - State of the Market
Utility Scale is Driving US PV Growth

Figure 1.1 Annual U.S. Solar PV Installations, 2000-2016

Cumulative US Solar PV Installations To Date > 42 GWdc

Utility Scale
Non-Residential
Residential

US Installed Capacity to Increase 3X by 2022

NREL—Solar Power as a Major Contributor to the US Grid

SunShot Vision
700GW by ‘50 in US
> 25% Electricity Share

figure 1. Solar capacity growth for selected SunShot Vision and RE Futures scenarios.

Corporate Adoption for the Right Reasons

“...we’re partnering with First Solar – to build ... a 130MW utility scale power plant.”

“...we are doing this because it is right to do, but you may also be interested to know that it’s good financially to do it ... because we have a fixed-price for the renewable energy...”

Tim Cook, CEO of Apple Inc.  
2015 Goldman Sachs Technology Conference
What Does it Mean for the Grid to be “Stable”

• Power generated from existing supplies must meet the loads at all times
  — If not then some load may be involuntarily turned off
  — Blackout (or Power Outage) can occur when power demands cannot be met from existing supplies

• Voltage remains within the specified acceptable range – e.g., +/-5% of "nominal" per unit (pu) line voltage
CAISO – Increasing Penetration Leads to Renewables Curtailment

~36 GW by ‘30

~22 GW by ‘20

Reduce Curtailment Through Increased Grid Flexibility

Source: Clyde Loutan, CAISO, “Demonstration of Essential Reliability Services by a 300-MW Photovoltaic Power Plant”
Flexible resources are being incentivized to meet net load demand curves

Example: Winter 2020

Load & Net Load (MW)

Net Load = Load - Wind - Solar

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Role of Utility-Scale PV Plants In Grid Stability & Reliability

• NERC identified essential reliability services to integrate higher levels of solar resources

• Utility-Scale PV Plants Provides

  ▪ Grid Friendly Features Required by NERC
    ✓ Voltage regulation
    ✓ Real power control, ramping, and curtailment
    ✓ Primary frequency regulation
    ✓ Frequency droop response
    ✓ Short circuit duty control
    ✓ Fault ride through

Utility-Scale PV Plant Contributes to Grid Stability & Reliability Like Conventional Generation

Source: NERC: 2012 Special Assessment Interconnection Requirements for Variable Generation
Plant Control System – Key Enabler for Grid Friendly Features

Operator Enters Set Points

Plant SCADA system

Operator

Power Plant Controller

PPC

Set Points

Grid Parameters

• Checks grid’s actual conditions and required set points
• Sends individual instructions to each inverter based on location, losses, and performance
• Controls quality of power coming out of the PV plant

Closed-loop controls at 100 milliseconds!

Patent No. 8,774,974. Real-time photovoltaic power plant control system
Dynamic Power Factor Regulation

Power Factor Set Point Changed from 0.98 to 1.0

Command Power Factor

Total Reactive Power

Measured Power Factor

Time in Seconds

0
-10
-20
-30
-40
-50

-4
-2
0
2
4
6
8
10

0
0.980
0.985
0.990
0.995
1.000

MVARS

Power Factor

Reaches 90% Steady State Value in ~ 3.2 seconds

Inverters Change VAr Output

Benefit of Plant Level Control System

With a central control system, inverters are individually controlled when needed to meet the plant limit ...

Output of Each Block

Plant Output Power

Increase in Inverter Power Output

Inverter Curtailed Locally

Variability Reduced

Plant Output Limit
AGUA CALIENTE

site: Yuma County, AZ, USA
size: 290MW
owners: NRG Energy and MidAmerican Solar

Reliable bulk power generation utilizing advanced plant controls and forecasting
Passage of Clouds at a 290 MW PV Plant

~20 minutes
Demonstration of Essential Reliability Services by a 300-MW Solar PV Power Plant
TESTS SUCCESSFULLY CONDUCTED ON 300 MW SOLAR PV PLANT

- **Power Ramping**
  - ✓ Ramp its real-power output at a specified ramp-rate
  - ✓ Provide regulation up/down service

- **Voltage Control**
  - ✓ Control a specified voltage schedule
  - ✓ Operate at a constant power factor
  - ✓ Produce a constant level of MVAR
  - ✓ Provide controllable reactive support (droop setting)
  - ✓ Provide reactive support at night

- **Frequency**
  - ✓ Provide frequency response for low frequency & high frequency events
  - ✓ Control the speed of frequency response
  - ✓ Provide fast frequency response to arrest frequency decline

Utility-Scale PV Plant Provides NERC Identified Essential Reliability Services
AGC Participation Tests – 300 MW Utility-Scale PV Plant

- 4-sec AGC (Automated Generation Control) signal provided to Plant Controller
- 30MW headroom
- Tests were conducted for
  - Sunrise
  - Middle of the day
  - Sunset
Morning AGC Test

AGC set point

Measured

Lower bound
Upper bound

30 MW

Power (MW)

Seconds
Regulation Accuracy of the PV Plant Exceeds Accuracy of Conventional Resources

Regulation accuracy by PV Plant is about 24-30 points better than fast gas turbines.

Blue bars taken from the ISO’s informational submittal to FERC on the performance of resources providing regulation services between January 1, 2015 and March 31, 2016.

Increasing Grid Flexibility to Meet Challenges of High Renewable Penetration

Key Summary – Solar’s Transition into Mainstream Generation Source

- **Solar** has the potential to contribute **up to 25% of global electricity by 2050**[^1].
  - Already on a path to grow to over ~700GW by 2020[^2]

- PV Solar electricity **already costs less** than new thermal generation in many markets

- To Meet Challenges in Growth of Solar Energy[^3]
  - Utility-scale PV Plant with **Grid Services Capability** can be dispatched (*when it is operating*) like a conventional plant ... supporting **grid stability and reliability**
  - **Need to increase grid flexibility** to reduce solar curtailment/ and realize its full potential

**Sources:**