Solving real problems with technology

Future PV Roundtable – Solar Power International 2019
Agenda

Part I

10:00
Welcome and introductions

10:05
PRESENTATION C&I Value stacking: the role of inverters in managing the underlying distributed energy resources and grid interaction and support, including virtual power plants.

10:15
PANEL DISCUSSION Meeting grid needs with solar & inverters: examining how inverters can supply essential grid services such as frequency & voltage regulation, as the grid moves from large spinning masses to electronic controls, as well as how solar & storage behind the meter can serve as flexible demand
PANEL DISCUSSION Explosion of cell & module technology: which designs can meet the challenges of mass production & stand the test of time?

11:05

Networking

11:55

Closing remarks

Future PV Roundtable – Solving real problems
C&I Value stacking

The role of inverters in managing the underlying distributed energy resources and grid interaction and support, including virtual power plants
Lior Handelsman
VP of Marketing and Product Strategy
Opportunity for C&I in Grid Services

Lior Handelsman

September 25th, 2019
Meet SolarEdge
SolarEdge in Numbers Q2 2019

13.1GW
of our systems shipped worldwide

Over 1.1M monitored systems around the world

17M
inverters shipped

$325M
Q2 2019 revenue

2,078
employees

40.8M
power optimizers shipped

Presence in 28 countries

13.1 GW
of our systems shipped worldwide

303 awarded patents and 240 additional patent applications
One-Stop-Shop for Smart Energy Solutions

- Smart Modules
- Residential and Commercial PV Inverters
- EV Charging
- Batteries, UPS, and EV Powertrains
- Monitoring Platform and Grid Services
- Smart Energy Management
Grid Challenges
Renewable Penetration

- Each year, more electricity is generated from renewable energy than in the previous year.
- Solar PV has exceeded 20% of the renewable share.

Source: https://www.ren21.net/gsr-2019/chapters/chapter_01/chapter_01/#target_192
Electrification of Transportation

- Approximately 18M EVs and hybrids will be on U.S. roads by 2030
  - 900% increase from 2020
- Leading to 53 GW of increased energy demand for charging, up from only 6 GW in 2020
- Potentially causing EV charging peaks that could surpass total capacity

Source: McKinsey, Citylab
A variety of extreme weather is occurring at increasing frequency, intensity, and duration. Severe weather is among the leading causes of large-scale power outages in the U.S.

Extreme Weather Is Causing More Major Power Outages
(major = at least 50,000 customers affected)

Source: Vox, Our Energy Policy
Aging Infrastructure and Network

- Parts of the energy network are >100 years old, 70% of transmission lines and power transformers are >25 years old
- Average power plant age is >30 years; plants built during the rapid expansion of power sector after WW2 are >40 years old
- Traditional generators are being retired, effecting an increasing amount of capacity


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Location and Depreciated Status of all U.S. Power Plants

Cyber Security

- Energy sector is one of the larger targets for cyber attacks
- Objective to cause equipment malfunction or failure, physical equipment damage, power disruptions, or blackouts
- U.S. Example:
  - March 5, 2019
  - Utility reported a ‘cyber event’ to the DOE
  - Blind spots caused by denial-of-service attack at a grid control center and several small power generation sites in California, Utah, and Wyoming
  - May not have been a full attack, but demonstrates grid vulnerabilities (i.e. in firewall interfaces)

Source: Energy.gov, E&E News, NPR

FY 2015 Incidents by Sector (295 total)
Fluctuating Energy Prices

- General trend of increasing annual energy prices
- Seasonal fluctuations with peaks in summer months
- Variation by customer type

### Annual Growth in Residential Electricity Prices

<table>
<thead>
<tr>
<th>Year</th>
<th>Growth</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>2.1%</td>
</tr>
<tr>
<td>2014</td>
<td>3.2%</td>
</tr>
<tr>
<td>2015</td>
<td>1.1%</td>
</tr>
<tr>
<td>2016</td>
<td>-0.8%</td>
</tr>
<tr>
<td>2017</td>
<td>2.7%</td>
</tr>
<tr>
<td>2018</td>
<td>0.0%</td>
</tr>
<tr>
<td>2019</td>
<td>1.1%</td>
</tr>
<tr>
<td>2020</td>
<td>0.7%</td>
</tr>
</tbody>
</table>

### U.S. Monthly Residential Electricity Price

- **Residential:** $12.89\$/kWh
- **Commercial:** $10.66\$/kWh
- **Industrial:** $6.93\$/kWh
- **Transportation:** $9.77\$/kWh

Source: EIA Short-Term Energy Outlook, EIA website
Opportunities
Overcoming Challenges

Some of the problems can be used as part of the solution

- Combining renewables, smart EV charging, and batteries can make the energy market more stable and cope with grid instability

Source: Utrecht University: Analysis of the impact of controlled charging and vehicle to grid on growth of electric vehicle and photovoltaic systems: a case study in Amsterdam
Batteries can provide up to 13 services for 3 different stakeholders.
C&I Opportunity

C&I may offer greater potential than residential for grid services

- Each site has a larger impact on the grid, but still distributed generation
  - Consume more energy
  - Produce more energy with larger roof space
- Larger variety of DERs that can be leveraged
- Specifically assist with duck curve ramp up - i.e. battery discharge in the evening
- Reduced acquisition costs per MW for grid services participation
- More value stacking opportunity
- Reduced communication costs per MW
Stacked Value Energy Management

Improving the economics of distributed energy resources

- Demand management (peak shaving)
- Maximized Self-Consumption
- Tariff Optimization (ToU)
- Grid Services
- Microgrid

Site-level and aggregated
Technology Requirements

- Smarter inverters: Fast communication/connectivity with high bandwidth, processing power, memory, interoperable
- Metering: Import/export, self-consumption, and grid sensing
- Predictive analytics, machine learning, and big data
- External interfaces: Pricing signal, weather information, etc.
- Batteries: Built to support high C rate, high energy throughput with unpredictable charging patterns, etc.
- Underlying DERs: Fast, accurate, fail safe, certified, interconnected (IoT), interoperable
- EV charging: Understanding usage patterns and interface with the driver to optimize charging times for driving needs in coordination with network needs
Cautionary Note Regarding Market Data & Industry Forecasts

This power point presentation contains market data and industry forecasts from certain third-party sources. This information is based on industry surveys and the preparer’s expertise in the industry and there can be no assurance that any such market data is accurate or that any such industry forecasts will be achieved. Although we have not independently verified the accuracy of such market data and industry forecasts, we believe that the market data is reliable and that the industry forecasts are reasonable.

Version #: V.1.0

Thank You!
Booth 1601
Panel discussion

Meeting grid needs with solar & inverters: examining how inverters can supply essential grid services such as frequency & voltage regulation, as the grid moves from large spinning masses to electronic controls, as well as how solar & storage behind the meter can serve as flexible demand.
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Peter Mathews
General Manager North America

Mahesh Morjaria
Vice President, Systems Development

Mark Ahlstrom
Vice President of Renewable Energy Policy
Combining PV, Storage and EV as a Grid Solution

- EV charging causes even faster evening ramp up
- Smart charging and storage solutions can help to balance the effects of PV and EV penetration

Source: Utrecht University: Analysis of the impact of controlled charging and vehicle to grid on growth of electric vehicle and photovoltaic systems: a case study in Amsterdam
Expanding Role of the Inverter

- Inverter manages multiple types of DERs
  - Storage
  - EV charging
  - Self-consumption
  - Home energy
- Manages and regulates smart grid
  - Takes aggregated commands and disaggregate them to underlying DERs
Features Required by NERC to be a Good Grid Citizen:

- Voltage regulation
- Active power control (ramping, Curtailment)
- Grid disturbance ride through (voltage and frequency excursions)
- Primary Frequency droop response
- Short circuit duty control

Sources:
(1) NERC: 2012 Special Assessment Interconnection Requirements for Variable Generation
Solar Plant Provides Essential Reliability Services

NERC: Essential reliability services
- Frequency Control
- Ramping capability or flexible capacity

Power Regulation
- AGC
- Up-Regulation
- Down-Regulation
- Frequency Regulation
- Flexibility

300 MW PV Plant

Source:
AGC: Automated Generator Control
Firm Dispatchable Solar with Storage

Storage enhances Grid Flexible Solar to:

- Firm and/or shift solar energy delivery to the grid
- Meet resource adequacy requirements
- Potentially provide black start capabilities

Firm Dispatchable Solar

- Firming
- Energy Shifting

Resource Adequacy

Black Start

Solar+Storage designed to deliver firm capacity and enhanced grid services

Grid Capabilities Enhanced w Storage
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DC-coupled PV + Storage Hybrid Resources

Hybridizing changes plant design
• Leads to dramatic internal design changes and higher effective renewable capacity factors
• Variability is reduced by pushing much of it into clipped region and controlling battery charge rate
• Many options to optimize layout, orientation, bifacial PV panels, etc.
• Optimized use of interconnection
Important Example: Frequency Response to an Event

Disturbance (e.g., loss of a large generating unit)

Primary frequency response stabilizes the frequency

Additional power from regulation and dispatch compensates for lost resources to bring the system frequency back to 60 Hz

Synchronous inertial response sets initial slope

Fast frequency response establishes the minimum frequency point ("nadir")

Figure from J. Eto, LBNL, https://www.ferc.gov/industries/electric/indus-act/reliability/frequencyresponsemetrics-report.pdf
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Panel discussion

Explosion of cell & module technology: which designs can meet the challenges of mass production & stand the test of time?
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CEO

Alex Chen
Head of Sales and Marketing

Kirsten Myers
R&D Director

PVEL
ET Solar
Heraeus
Module Power: Historical and Forecast

Historical

Forecast

Source: Bloomberg NEF

Source: PVEL
Which Technology Will Get Us There?

- The industry is now pursuing many promising technologies
- Modules are getting larger
- With all new technologies come new risks – Test, Test, Test!!

<table>
<thead>
<tr>
<th>Technology</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Larger Wafers</td>
<td>156.75 → 158.75 → 161.7 → 166</td>
</tr>
<tr>
<td>Thinner Wafers</td>
<td>1.5 c / Wp per 10 um (0.01 mm)</td>
</tr>
<tr>
<td>Half-Cell</td>
<td>~5+ Wp at STC</td>
</tr>
<tr>
<td>Shingling</td>
<td>~10+ Wp at STC</td>
</tr>
<tr>
<td>Bifacial</td>
<td>3 – 20% yield gain</td>
</tr>
<tr>
<td>Tandem</td>
<td>30%+ efficiency</td>
</tr>
</tbody>
</table>

Source: Munnik, Semco, PV CellTech 2018

![Graph showing average industrial cell efficiency from 2010 to 2030 with various technologies including Silicon based Tandem cells, Passivating contacts IBC, Passivating contacts Heterojunction, PERC, and AI-BSF. Each technology shows a different trend and efficiency gain over the years.](Image)
Forecast vs. Actual Module Price

From NREL study, based on 17 different market forecasts

- Raw materials
- Factory throughput & utilization
- Profit margins
- Cell & module efficiency
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R&D Director
High Efficiency Cell Technology Route—Upgrade Route

SiNx Coating equipment
Laser grooving equipment

Homogenous knot
Thoroughly change the front electrode structure

Heterojunction completely change the grid line structure
TOPCon Craft Route

TOPCon (Tunnel Oxide Passivated Contact) technology is to prepare an ultra-thin tunneling oxide layer and a highly doped polysilicon thin layer on the back side of the cell, which together form a passivation contact structure, as shown in the Figure. This structure provides good surface passivation for the back side of the silicon wafer, and the ultra-thin oxide layer can tunnel the multi-sub-electron into the polysilicon layer while blocking the minority sub-hole recombination, and the electrons are laterally transported and collected by the metal in the polysilicon layer, thereby greatly reduced contact recombination current, and the open circuit voltage and short circuit current of the cell are improved.
In theory, TOPCon can be implemented on both P-type and N-type silicon wafers.
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**PASSIVATED CONTACTS**

**PROs:**
- Low Recombination Current
- High Voc
- High Efficiency
- Add-on to existing n- or p-type lines

Depending on who, and details of structure, also known as:
- TOPCon™
- MonoPoly™
- POLO™
- Poly Si
PASSIVATED CONTACTS - INDUSTRIAL

**N-type cell with PolySi Contacts**
- Screen printed Ag
- AR Coating
- AlOx passivation
- p+ Boron emitter
- n-type wafer
- Tunnel oxide
- n+ Polysilicon
- AR Coating
- Screen printed Ag

**P-type cell with PolySi Contacts**
- Screen printed Ag
- AR Coating
- Thick n+ Polysilicon
- Thin n+ Polysilicon
- Tunnel oxide
- p-type wafer
- Local Al BSF
- AlOx passivation
- Screen printed Al

**Champion:** 24.58% by Trina
>23.0 % Ave Mass Pro (+Bifacial)

**Challenges:**
- Cost: +10% wafer; 2X Ag
- Add Vapor Deposition (SiO2 + PolySi)
- Throughput – slow Poly growth
- Metallization of thin poly layers (150 nm)

**Challenges:**
- Optical Abs by Poly
- Metallization of thin poly layers (<30 nm)
- OR
  “Structured” Poly only under contacts
HETEROJUNCTION

Champion: 24.32% by Hanergy
Lowest LCOE, Bifacial, lower temp coeff.

Challenges:
High CapEx, 2X Ag
Unique Cell Line
Underdeveloped value chain

Options to Lower Cost:
Smartwire or MBB
Narrower FL (Challenge!)
Dual Printing
P-type wafer

Fewer Process Steps

Modified from Meyer Burger
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R&D Director
Networking session
Solving real problems with technology

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