An Overview of Power System Transformation – The Impacts of New Technologies and Innovations

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There is an established and quickly growing body of knowledge on the successful management of modern power systems in transition.

The ‘Status of Power System Transformation’ series codifies global policy, market and technological developments and trends in the power sector.
Overview of Select Trends

1. Technology Cost/Performance Improvements
2. Power System Flexibility: A Global Priority
3. Decentralization of Supply
4. Electrification and Sector Coupling
5. Shifting Planning Paradigms and Practices
Not Covered Today (Sorry!)

• Utility business model and regulatory innovations*
• Wholesale energy market price formulation re-design
• Transportation electrification*
• Trends in digitalization, advanced metering infrastructure (AMI), and cyber security
• Resiliency efforts and microgrids
• Community solar initiatives
• “Transactive” peer-to-peer energy trading futures
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Variable renewable energy costs continue to decline

Image Source: IRENA Renewable Power Generation Costs in 2018
How is this happening?

Competitive tenders/auctions are the key driving force for cost reductions

Source: GTM
The Broader Storage Ecosystem

Unsuitable for distributed applications
- Pumped Storage
- Hydropower
- Compressed Air Energy Storage
- Thermal Energy Storage
- Flow Batteries
- Sodium-based Batteries

Suitable for distributed applications
- Superconducting Magnetic Energy Storage
- Supercapacitors
- Flywheels
- Nickel-based Batteries
- Lead Acid Batteries
- Lithium-ion Batteries

Large capacity, difficult to site, difficult to scale down

Stringent operating and housing requirements

Image Source: Zinaman et al. (forthcoming)
Lithium-ion Batteries: Why all the hype?

85% cost reduction since 2010 due to technology improvements, economies of scale, manufacturing competition

To-date, storage deployment following similar trajectory to PV deployment in early 2000s

**Lithium-ion battery price survey, 2010-18 ($/kWh)**
*Source: Bloomberg New Energy Finance (March 2019)*

Lithium–ion battery price survey results: volume–weighted average

Battery pack price (real 2018 $/kWh)

<table>
<thead>
<tr>
<th>Year</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>1,160</td>
</tr>
<tr>
<td>2011</td>
<td>899</td>
</tr>
<tr>
<td>2012</td>
<td>707</td>
</tr>
<tr>
<td>2013</td>
<td>650</td>
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<td>2014</td>
<td>577</td>
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<tr>
<td>2015</td>
<td>373</td>
</tr>
<tr>
<td>2016</td>
<td>288</td>
</tr>
<tr>
<td>2017</td>
<td>214</td>
</tr>
<tr>
<td>2018</td>
<td>176</td>
</tr>
</tbody>
</table>

**Projected Cumulative Global Storage Deployment 2016-30 (GW)**
*Source: Bloomberg New Energy Finance (November 2017)*

- **Behind-the-meter**
  - 2016: 3
  - 2027: 69
- **System-level**
  - 2016: 3
  - 2027: 69

85% cost reduction since 2010 due to technology improvements, economies of scale, manufacturing competition

To-date, storage deployment following similar trajectory to PV deployment in early 2000s
Record-breaking utility-scale solar + storage prices

The New Record?

**Developer:** 8Minute Energy  
**Offtaker:** LADWP  
**PPA Term:** 25 years  

400 MW Solar @ **USD $19.97/MWh** (≈75 BRL/MWh)  
200 MW / 800 MWh Storage @ **USD $13.00/MWh** (≈49 BRL/MWh)  

Designed to maximize transmission capacity utilization  
Hours of Operation: ~7am – 11pm

Source: Utility Dive (2019)
Most Common Battery Use Case: Frequency Regulation

- Significant deployment for frequency regulation (regulating reserves/secondary frequency response)
- Often most cost effective early application
  - Short duration requirements
  - High utilization of storage assets

Source: US Energy Information Administration (2017)
Emerging Trend:
Battery Hybridization with Conventional Power Plants

Pairing battery electricity storage systems with peaking plants can allow for the provision of spinning reserves without the power plant actually running.
A Virtuous Cycle? Higher penetrations of wind and solar may increase the market potential for batteries.

Some power systems are nearing a tipping point for 4-hour storage providing capacity services instead of conventional generators.

Innovative technology can bring innovative business models

Example: GI Energy + ConEd

- Four 1 MW / 1MWh batteries located in front-of-the-meter at customer sites throughout NYC area
- Located in constrained network areas
- Customer receives lease payment
- **Regulated:** ConEd granted priority dispatch during peak local demand
- **Competitive:** GI Energy can otherwise sell flexibility services on NYISO
- **Innovation:** Value stacking across regulated and competitive market segments

Image Source: T&D World
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Power system flexibility has become a global priority

Figure source: NREL Report No. FS-6A20-63039
Different levels of VRE penetration require an evolving approach to providing power system flexibility.

Growing Recognition of Importance of “Institutional” Flexibility

- Faster power system / market dispatch*
  - Reduces flexibility requirements
- Better wind and solar production forecasting
  - Reduces flexibility requirements
- Improved balancing area coordination
  - Increases access to flexibility resources
- Smart planning and procurement strategies
  - Integrated generation-transmission planning finds system-optimal VRE resources to reduce aggregate flexibility requirements
- Flexible contract structures for power plants
  - Avoiding “lock-in” of long-term take-or-pay contracts enables flexible operation and leaves headroom for lower cost resources at a later time
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Key Trend: Decentralization of Supply

• Increasing permeation of distributed energy resources (DER) in power markets

• Geographically diverse spread of power generation resources
  – Predominantly variable renewable energy resources, but also batteries and natural gas to some extent
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The Utility Perspective: Distributed Solar Challenges Our Traditional Business Model

- Selling power creates revenue to pay for infrastructure
- DPV deployment reduces revenues and may reduce regulated capital expenditures
- DPV most appealing and accessible to customer groups that typically subsidize the system
How big are these expected utility tariff impacts?

Usually smaller than predicted...

Figure 1: Summary of retail tariff impacts resulting from 3,000 MW of DPV deployment in Thailand in 2020 by distribution utility and analysis scenario compared with median $F_t$ change from 2007-2017.

Note: SAT = satang. 100 Satang = 1 Thai baht (THB)
Categories of potential utility responses to DER

Constrain
- Impede program development, impose fixed charges, restrictive permitting and interconnection, etc.

Enable
- Establish passive regulatory frameworks for compensation and interconnection, allowing market to function without intervention

Accelerate
- Create proactive regulatory frameworks for interconnection and compensation, providing market with framework to monetize value create by innovation

Transform
- Restructuring of traditional utility business model, establishing new revenue streams, performance regulation and incentives, etc.

Enable/Accelerate Strategy: Alternative Retail Rate Structures to Ensure Cost Recovery

<table>
<thead>
<tr>
<th>Rate Type</th>
<th>Description</th>
</tr>
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</table>
| Standard Rate                   | • Default customer rate.  
• Volumetric kWh energy charge + fixed charge + adders.                                                                                       |
| Increased Fixed Charge          | • Increasing the fixed charge component of the bill  
• Commonly proposed option (may incl. lower energy charge)                                                                                     |
| Minimum Bill                    | • Sets the lower limit that a customer will pay each billing period                                                                                                                                     |
| Nonbypassable Volumetric Charge | • Volumetric charge that cannot be offset by DPV kWh credits  
• May require additional metering; essentially Net Billing                                                                                      |
| Time-of-Use Energy Rates        | • Add time-based pricing for consumed/exported energy  
• Volumetric kWh energy charge + fixed charge + adders.                                                                                           |
| Demand-Based Rate               | • Demand charge component of the bill is based on the maximum kW used over specified time interval; coincident vs. non-coincident  
• Typically has a lower energy charge                                                                                                             |
### Transform Strategy: New Utility Business Models

There are many ways for utilities to create new revenue from DER

<table>
<thead>
<tr>
<th>Category</th>
<th>Question</th>
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<tbody>
<tr>
<td>Customer Acquisition</td>
<td>Who reaches out to customer to garner interest?</td>
</tr>
<tr>
<td>Transaction Facilitation</td>
<td>Who brings the project to financial close, including pricing the DPV system for the customer?</td>
</tr>
<tr>
<td>Project Design / Construction (EPC)</td>
<td>Who installs the system?</td>
</tr>
<tr>
<td>Interconnection Certification and Registration</td>
<td>Who is responsible for certifying the system and registering with the distribution?</td>
</tr>
<tr>
<td>PV Supply Chain</td>
<td>Who manufactures and/or procures the DPV system components?</td>
</tr>
<tr>
<td>Project Financing</td>
<td>Who invests the capital to build the system?</td>
</tr>
<tr>
<td>Facilitation of Financing</td>
<td>Who ensures that financing payments are delivered?</td>
</tr>
<tr>
<td>DPV System Ownership</td>
<td>Who is the legal owner of the DPV system?</td>
</tr>
<tr>
<td>DPV Site Ownership</td>
<td>Who owns the location where the DPV is sited?</td>
</tr>
<tr>
<td>Distribution Grid Management</td>
<td>Who is responsible for investing and operating the distribution grid under increased DPV penetration?</td>
</tr>
</tbody>
</table>
Utility “Facilitation” Business Model

- Residential customers are at a significant disadvantage during procurement, leading to higher system pricing
  - Potential justification for monopolistic force entering into competitive/private market

- Utility plays role of:
  - Periodic aggregation of customer interest
  - Competitive procurement (and financing) facilitator on behalf of customers
  - Can offer both individual and community DPV systems
Trend in USA: Storage-plus-DPV under NEM

- **NEM with time-invariant rates:**
  - grid is effectively a free-to-access financial battery
  - minimal economic benefit for storage-plus-DPV
  - some reliability benefit, if valued

- **NEM with time-of-use or demand-based charges**
  - *may be significant incentive* to install storage by exporting / avoiding consumption during peak periods
  - This is valuable to power system broadly if retail rates are sufficiently granular
Trend: Emergence of DER Aggregation

Example: South Australia’s AGL Virtual Power Plant

1000 residential BTM storage-plus-DPV customers (5 MW, 12 MWh)

Intended Use:
- Voltage support for distribution feeders with high solar penetrations
- Capacity and frequency regulation at wholesale market level

Customer Compensation:
- $1,000 incentive to install storage
- 1-year contract: $100 signing bonus, $45 / 3 months (bill credit)
Trend: Emergence of DER Aggregation

Fortrum Virtual *Thermal* Energy Storage Aggregation Plant

- Pilot program: ~2,000 residential water boilers aggregated
- Fixed bill credit for customer
- Staggered use
Trend: Evolving regulatory frameworks for distribution companies accelerating DER investments

• Regulatory incentives are driving distribution utilities to weigh traditional grid capacity upgrades against emerging alternatives

• Examples:
  – New York – Non-wires Alternatives
  – Australia – The $5M Rule
  – California – Demand Response Auction Mechanism
  – U.K. – Network Innovation Competition
Key Trend: Decentralization of Supply

• Increasing permeation of distributed energy resources (DER) in power markets

• Geographically diverse spread of variable renewable energy resources
Geographically dispersed fleet of supply-side resources

• Smaller projects due to use of modular technologies
• Broader distribution of economic benefits
  – Creation of good-paying long-term rural jobs
  – Land lease payments to rural communities
• Potential need for more network infrastructure
  – Project development timeframe for network infrastructure far exceeds renewable energy
    • Greater need for proactivity in transmission planning
Large centralized thermal power plants are increasingly being retired in lieu of a more economically competitive and geographically diverse portfolio of smaller-scale wind, solar, natural gas, and battery energy storage resources, as well as more customer-sited DERs.

**Trend**: Taxpayer and ratepayer-financed “Just Energy Transition” initiatives to help re-train thermal power plant staff.
In the long run, the trend toward decentralization may lead to more broad-based and resilient local economic growth, where the future loss of a large power sector enterprise is less likely to significantly depress local economies.

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Select options for electrification of heating and transport

Sector coupling efforts have the potential to enroll new flexible loads at scale to enhance power system flexibility.
A Virtuous Cycle: Positive feedback between declining grid-based carbon intensity and electrified end uses

As electricity supply becomes increasingly decarbonized, the benefits of electrification grow with positive feedback.
Cyber security implications of digitalization and electrification - example: Electric Vehicles

- Communication between vehicles and grid/building are entry pathways for security breaches

- Vehicle software or firmware is most likely point of entry
- Malware could damage or infect charging infrastructure or vehicles
- Emerging field of research and development

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Planning paradigms and practices are shifting.

How we have planned, operated and even conceptualized the power system is driven by accommodating the technology that provides the most energy for the lowest cost.
We are now re-designing our approach to the power system based on the lowest cost source of bulk power generation

- **Energy volume contribution** is an indicator of the extent to which a resource provides low-cost, bulk energy to satisfy demand over a given time period.

- **Energy option contribution** is an indicator of the extent to which a resource is *available* to satisfy demand for energy and other critical system services over a given time period.
Growing Integration in Power System Planning Exercises

• Integrated planning incorporating distributed energy resources

• Integrated generation and network planning
  – Integrated or hybridized modelling techniques
  – “Renewable energy zone” process

• Integrated planning between the power sector and other sectors
  – e.g., natural gas, transportation and urban planning

• Integrated inter-regional planning
QUESTIONS?

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