Modernizing the U.S. Electricity System

Presentation to the U.S. National Academies of Sciences, Engineering, and Medicine's Committee on Modernizing the U.S. Electricity System

Tim Heidel

May 13, 2019

*** All opinions and perspectives in this presentation are my own and do not necessarily reflect the views or positions of my current or former employers.

My background

2009-2011

2012-2017

Power electronics programs:

- ADEPT
- Solar ADEPT
- SWITCHES

Power systems programs:

- GENI
- GRID DATA
- GO Competition

2017-2018

Federally funded R&D programs focused on electric cooperative utility data analytics and cybersecurity

2018-Present

Investing in early stage companies that can significantly reduce global greenhouse gas emissions

Focus sectors:

- Electricity
- Transportation
- Buildings
- Manufacturing
- Food & Agriculture

*** All opinions and perspectives in this presentation are my own and do not necessarily reflect the views or positions of my current or former employers.

Committee questions

- *What is your vision for the US/NA electric system in 10, 20, and 30+ years?*
- *What is your list of top RD&D challenges and top policy challenges?*
- *What trends do you see in international RD&D investments and what can the US learn?*
- *Where do you see technology advancements in one area illuminating needs in others?*
- *Specific areas of interest:*
  - *Power electronics for grid applications*
  - *Accommodating electricity demand changes*
  - *Asynchronous generation integration and control*
  - *Transmission expansion*
  - *Electricity innovation trends*

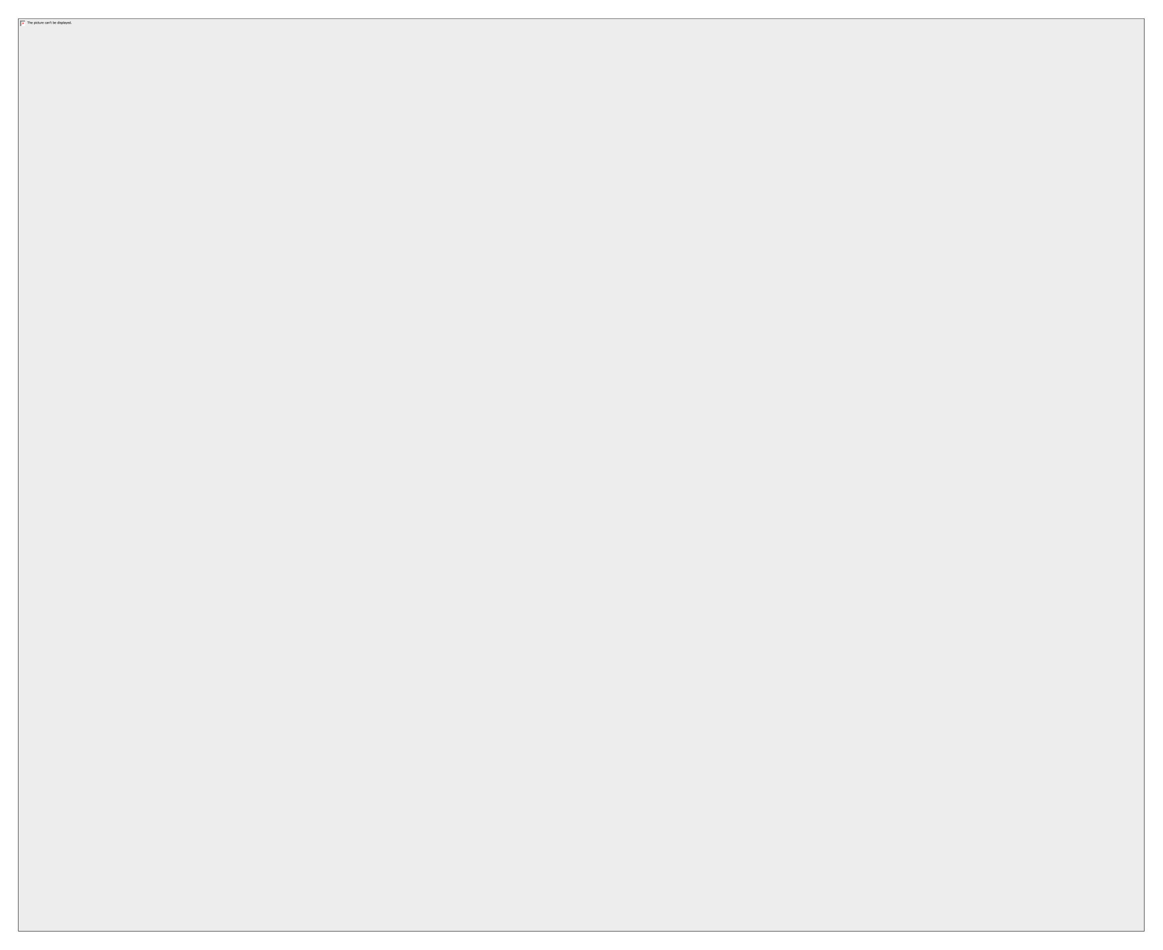
New, emerging electricity system challenges

- Aging infrastructure
- Desire for increased infrastructure resiliency
- Increasing interdependency of critical infrastructures
- Changing generation portfolios (fossil to renewables)
- Distributed energy resources growth (incl. electric vehicles)
- Changing consumer requirements (increased control, visibility)
- Increasing sophistication of cybersecurity threats

Safety, reliability, and affordability are non-negotiable

Electricity sector poised for growth, climate leadership

World installed capacity is ~ 6 TW, >10 TW by 2050



IEA World Energy Outlook 2018

Median IPCC scenarios: electricity sector emissions reduced 50% by 2030, 100% by 2050

Requires ~4 TW carbon free gen by 2030, ~8 TW by 2050

IPCC AR4 Summary Fig SPM.14

Electricity decarbonization innovation priorities

Low Carbon Generation

- Ultra low cost of renewable generation (wind and solar)
- Dispatchable low carbon generation
- Business models to accelerate generation transition

Managing grid operations

- Tools to maintain, optimize supply/demand balance (despite variability/uncertainty)
- Controls to ensure sufficient grid frequency response (low inertia)
- Systems to manage voltage/reactive power throughout grid

Transmission, Distribution, Substations

- Higher power capacity transmission (ac & dc)
- Multiterminal HVDC networks
- Power flow controllers (power electronics
- Scalable, low cost storage
- Dynamic, adaptive protection systems
- Automated network reconfiguration

Dispatchable Electricity Demand

- Real-time forecasting and situational awareness of demand-side flexibility
- Prioritization and scheduling (dispatch) electricity demand (including in real-time)

Image Source: MIT Future of the Electric Grid Study

Keys to operating low carbon electricity systems

- **Understanding**

  Improved system state awareness & visibility

- **Controls**

  Power flow control & dispatchable demand

- **Optimization**

  Faster, more robust, scalable algorithms

- **Architecture**
  - Full utilization of all resource capabilities

Keys to operating low carbon electricity systems

Understanding
- Data Analytics & Visualization
- Generation, infrastructure, load forecasting
- Synchronized grid sensors

Controls
- MV & HV solid-state power electronics
- Demand dispatch
- Adaptive, dynamic protection

Optimization
- Distributed Energy Resource Management Systems (DERMS)
- Decentralized (peer-to-peer) resource optimization
- Autonomous, reliable, dynamic grid controls (incl. protection)

Architecture
- Real-time distribution system management
- T&D Operations & Planning integration
- Interoperability/ Interconnection Standards

Power electronics: Enabling active flow control

- HVDC, FACTS, and solid-state transformers will improve grid control, capacity utilization
- Increasing dominance of modular architectures, offering improved performance and control despite Si power device limitations
- Circuit topology, system design innovations continue to offer important opportunities

KEY TECH OPPORTUNITIES

- Power flow controllers can significantly increase infrastructure performance. Key recent examples:

Increases or decreases the reactance of a transmission line, thereby pushing power away from or pulling more power towards the circuit on which it is installed.

Allows bi-directional, controlled exchange of real and reactive power between adjacent distribution feeders, enabling increased reliability and DER hosting

- Increasing VSC HVDC voltage & power capacity will offer easier route to integrating remote renewables
- Multi-terminal HVDC network technologies would improve reliability and reduce cost of renewables integration, improve system reliability and resiliency, and could enable true macrogrids
- Solid-state transformers at key network nodes (including transmission/distribution interfaces) could offer numerous benefits: Must meet or exceed performance of conventional transformers (99% efficiency, < $30/kVA)

Power electronics: SiC

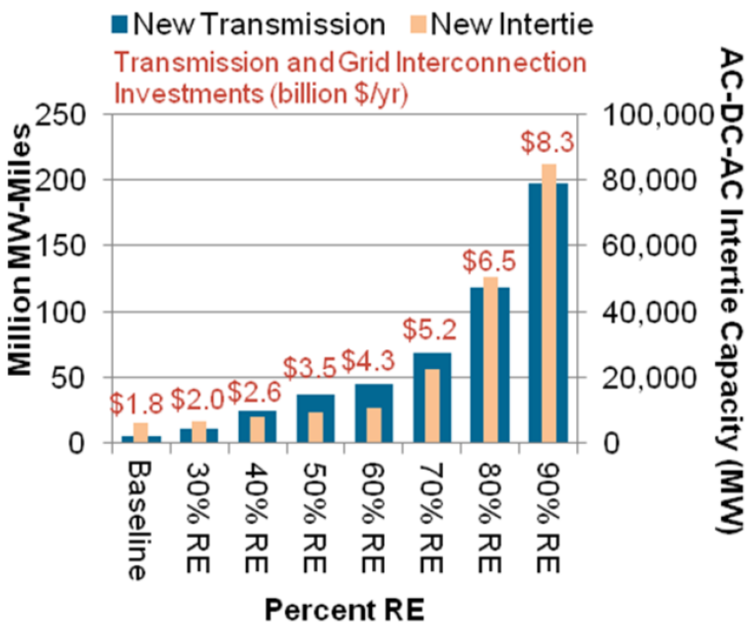
- Silicon Carbide (SiC) offers lower system cost and higher performance in most applications
  - Electric vehicles will drive rapid SiC growth, maturity, and cost reductions
  - Packaging remains a key bottleneck to fully utilizing material entitlement

- SiC in grid applications:
  - Low SiC current ratings limit high power utilization: device and packaging innovation needed to enable high power
  - SiC adoption will enable far lower complexity (fewer modules or new system topologies)
  - Relatively small existing market for devices > 2kV
- Materials beyond SiC?
  - Bulk GaN is theoretically superior, but lack of substrates and rapid SiC growth may make it very challenging for GaN to catch up and compete
  - New device categories for >> 25kV devices (photoconductive switches, gas tubes, etc.) on the horizon but remain at a very early stage

P. Friedrichs and M. Buschkuhle, "The Future of Power Semiconductors: Rugged and High Performing Silicon Carbide Transistors," EE Power Technical Article, April 1, 2016, https://eepower.com/semiconductors/future-power-semiconductors-rugged-and-high-performing-silicon-carbide-transistors

Long distance, high capacity transmission

- High capacity, long distance transmission offers numerous benefits, access to best renewables
- New right-of-ways (ROWs) are increasingly difficult to build, especially long distance
- New planning mechanisms needed, but ideal solution not obvious (many stakeholders, priorities)



(a) New transmission capacity[a] by 2050, and average annual investments from 2010–2050

National Renewable Energy Laboratory. (2012). Renewable Electricity Futures Study. Hand, M.M.; Baldwin, S.; DeMeo, E.; Reilly, J.M.; Mai, T.; Arent, D.; Porro, G.; Meshek, M.; Sandor, D. eds. 4 vols. NREL/TP-6A20-52409. Golden, CO: National Renewable Energy Laboratory. http://www.nrel.gov/analysis/re_futures/

- HVDC necessary for long distance, power electronics drive capacity limits, project scale limits pace of innovation
- Overcoming transmission deployment challenges:
  - Reuse of existing ROWs: Reconductoring and/or dc conversion
  - Utilization of alternative ROWs: Highways, pipelines, railroads, telecom
  - New conductor technologies promise increased capacity
    - Low sag composite core conductors
    - Superconducting transmission
    - Gas-insulated transmission lines (urban delivery)
- Transmission macrogrids: Who? How? Where? When?

Demand side flexibility

- Coordinating large fleets of demand side resources could offer a significant system flexibility
- Experts seem to believe 30% of peak load could be made flexible (> 230 GW in U.S.)
- Advances in communications and IOT will make cost-effective real-time, granular dispatch feasible

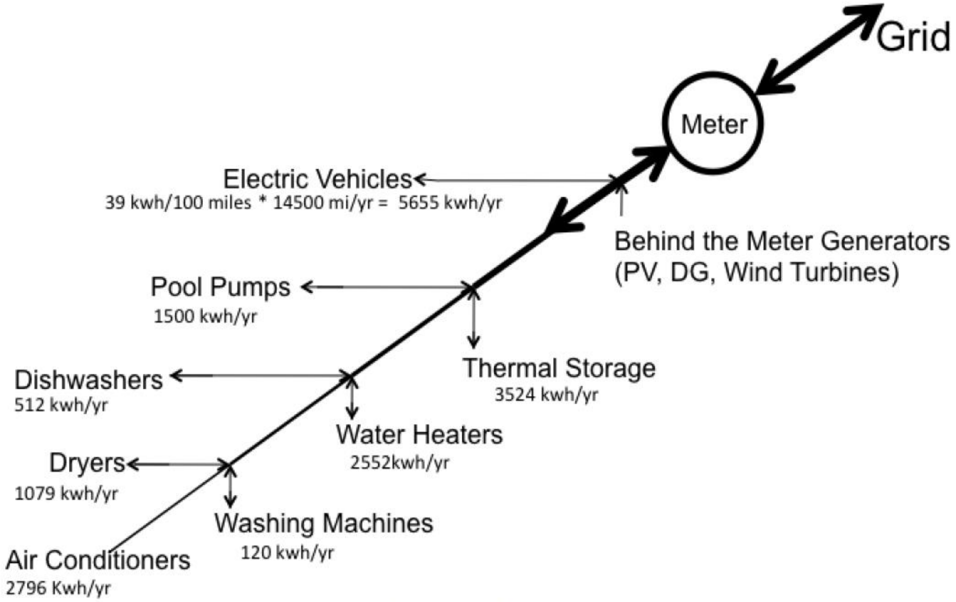


Figure 7: Demand Dispatch Resources

NETL/DOE Technical Report, "Demand Dispatch – Intelligent Demand for a More Efficient Grid" (2011), https://www.smartgrid.gov/files/DemandDispatch_08112011.pdf

- Demand dispatch requirements:
  - Customer quality-of-service cannot be impacted, very low willingness to pay
  - Dispatch must be coordinated to ensure bulk power system benefits without adverse distribution system impacts
  - Low customer/device acquisition costs required, automated commissioning essential?
  - Cybersecurity must be fully designed in from the start

Example: Plug-in Electric Vehicles

- Plug-in cars sold in 2018 (U.S. only): 360,914
- Assuming 7kW (Level 2 Charging): 2,526 MW
- Total Storage Capacity: 17,795 MWh

Sales data: https://insideevs.com/

Asynchronous generation integration and control

- Power system control will increasingly rely on asynchronous generation controls
- Uncertainty and perceived risk could significantly slow transition to renewables
- Emerging market microgrids and island grids provide important early opportunities for learning and large-scale testing

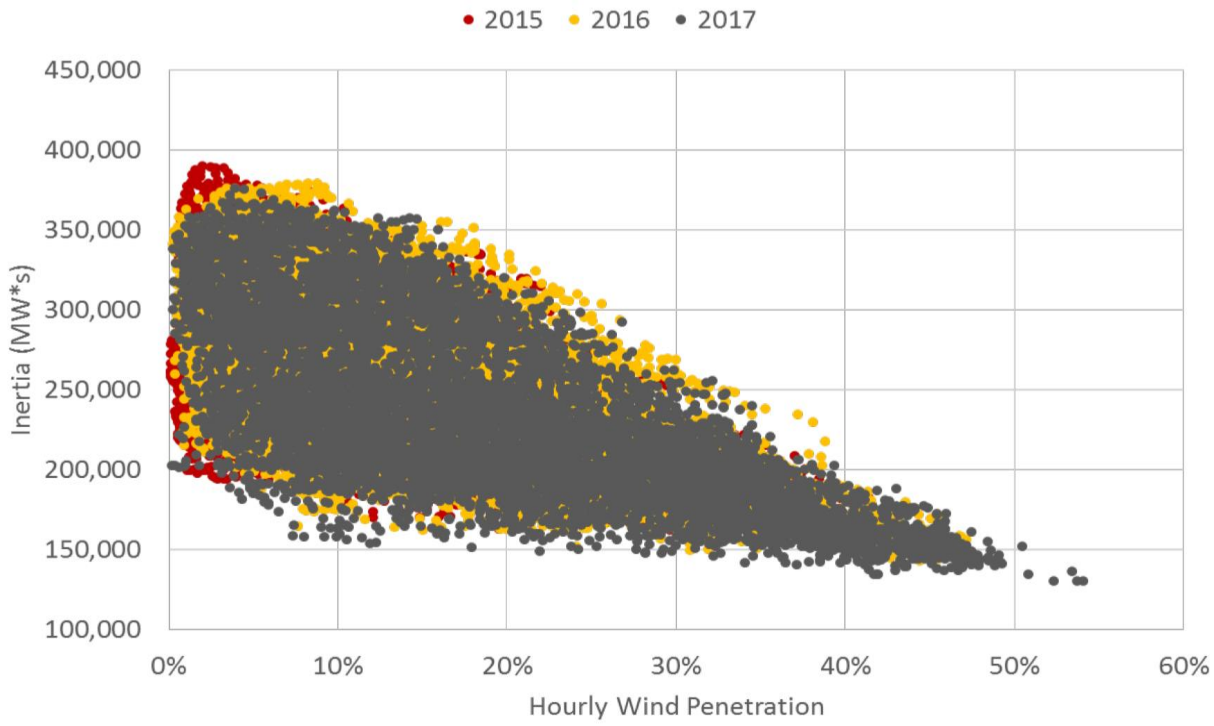


Figure 4: Correlation between Wind Penetration and Inertia in 2015, 2016, and 2017

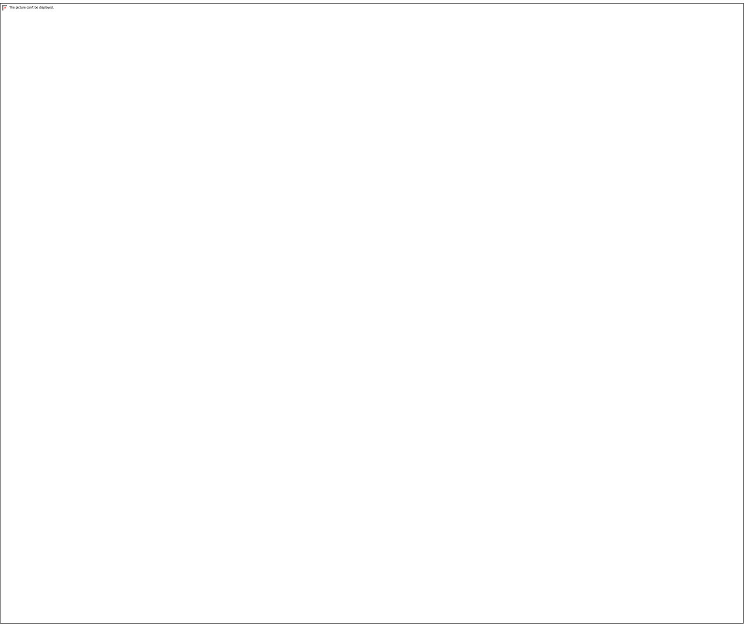
"Inertia: Basic Concepts and Impacts on the ERCOT Grid," ERCOT Whitepaper (Version 0), April 2018, http://www.ercot.com/content/wcm/lists/144927/Inertia_Basic_Concepts_Impacts_On_ERCOT_v0.pdf

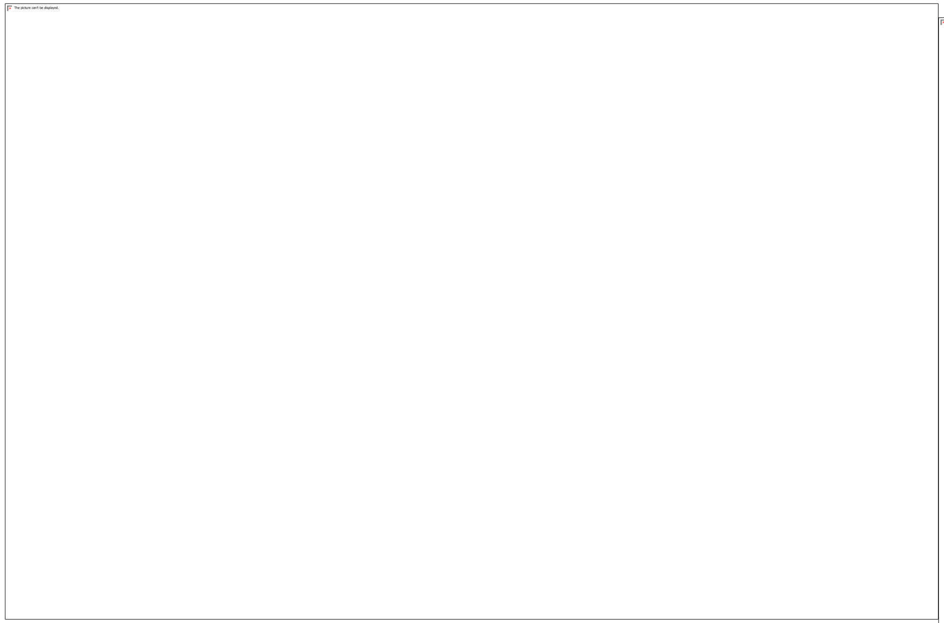
- Architectures for control at all time-scales critically important to get right
- Controls must integrate bulk power and local (distribution) requirements
- Devices/controls must be field upgradeable as algorithms as continuous improvement and tuning may be necessary
- Cybersecurity will be a key consideration, may bias towards more decentralized solutions

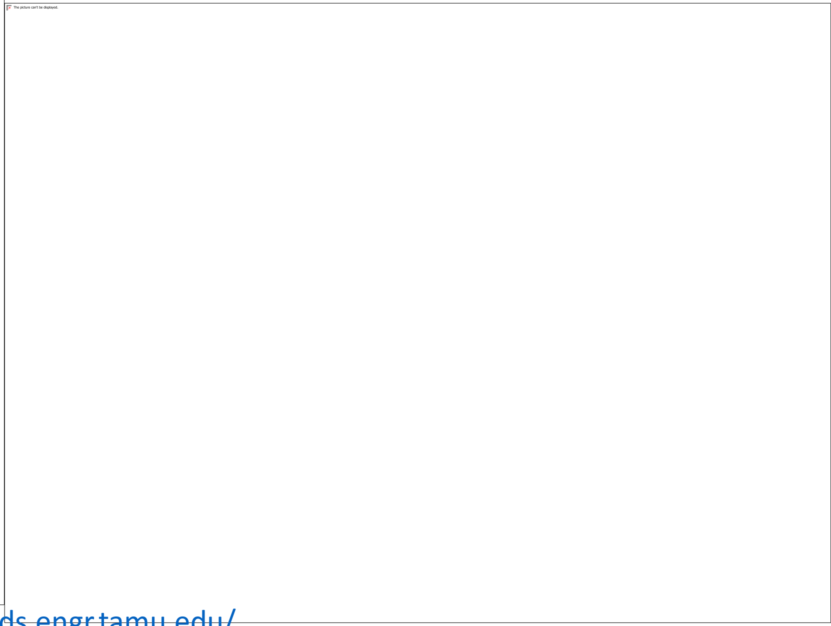
Electricity system innovation challenges

- All safety-critical industries (appropriately) struggle to adopt innovations quickly
- Competitive dynamics and power sector regulatory environment compound these challenges
- Lack of validated, large-scale, realistic, public data hurts effectiveness of power system research
- Successful technology pilot demonstrations rarely result in rapid large-scale deployment
- Long sales cycles, lack of technology adoption urgency prevents early stage investments

ARPA-E GRID DATA Program: Large-scale, realistic, validated, open-access power system OPF datasets/models







https://electricgrids.engr.tamu.edu/

Questions?

Tim Heidel

tim@b-t.energy