ENGINEERING AT ILLINOIS

COMPUTE-ENERGY-NEXUS WORKSHOP

PowerRox™

Keeping Both the Grid and Load Happy in Multi-MW Data Center Implementations

Brian Zahnstecher, Principal, IEEE Senior Member

Monday, December 8, 2025

Chair [Emeritus], *SF Bay IEEE Power Electronics Society (PELS)*
Chair*, IEEE PELS Sustainability "GREENS" Ad-hoc Committee*
Regional Chair*, IEEE PELS Regions 1-3*
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Co-chair*, PSMA Energy Harvesting Committee*
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Co-founder/Co-chair*, IEEE 5G Initiative Roadmap, Energy Efficiency WG*
Co-chair*, IEEE Future Networks Initiative (FNI) Webinar Series*
Co-founder/Co-chair*, EnerHarv Workshop*
Co-founder/Co-chair*, IEEE 5G Energy Efficiency Tutorial*

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Food for Thought

News

Scientists Discover Oil Originally Buried Deep Underground By Early Humans Desperate To Shield Humanity From Its Consequences

Published: October 21, 2019

IMAGE CREDIT: *"Scientists Discover Oil Originally Buried Deep Underground By Early Humans Desperate To Shield Humanity From Its Consequences," The Onion, October 21, 2019. [Online]. Available: https://theonion.com/scientists-discover-oil-originally-buried-deep-undergro-1839235246/.*

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Brian Zahnstecher is a Sr. Member of the IEEE, Chair (Emeritus) of the IEEE SFBAC Power Electronics Society (PELS), IEEE PELS North America Regional (R1-3) Chair, Chair PELS Sustainability "GREENS" Ad-hoc Committee, Power Sources Manufacturers Association (PSMA) Board of Directors (Emeritus) and now Advisory Council, authors the quarterly Power Rocks! column for IEEE Power Electronics Magazine (PEM), is Co-founder & Chair (Emeritus) of the PSMA Reliability Committee, Co-chair of the PSMA Energy Harvesting Committee, Co-founder & Co-chair of the EnerHarv workshop, and is the Principal of PowerRox. He Co-chairs the IEEE Future Networks (formerly 5G) webinar series and is a founding Co-chair of the IEEE International Network Generations Roadmap (INGR) Energy Efficiency Working Group and has lectured on related power and sustainability topics at major industry conferences. He sits on Advisory Boards of major conferences like Sensors Converge & DesignCon.

He previously held positions in power electronics, most recently with Claros (Sr. Principal Energy Efficiency Architect), as well as industry leaders Emerson Network Power (now Advanced Energy), Cisco, and Hewlett-Packard. He has been a regular contributor on power and sustainability topics to the industry as an invited keynote speaker, author/columnist, workshop participant, session host, roundtable moderator, and volunteer. He has over 20 years of industry experience and holds Master and Bachelor degrees from Worcester Polytechnic Institute.

Overview

- Rx Massive Loads, Massive Transients
- Rx Nexus of Utilities & Data Centers
- Rx Nexus of Academia, Industry, & Government
- Rx Tremendous Opportunities
- Rx Summary & Conclusions
- Rx Q & A

"Emancipate yourselves from mental slavery
None but ourselves can free our minds
Have no fear for atomic energy
'Cause none of them can stop the time"
– Bob Marley, Redemption Song

Massive Loads, Massive Transients

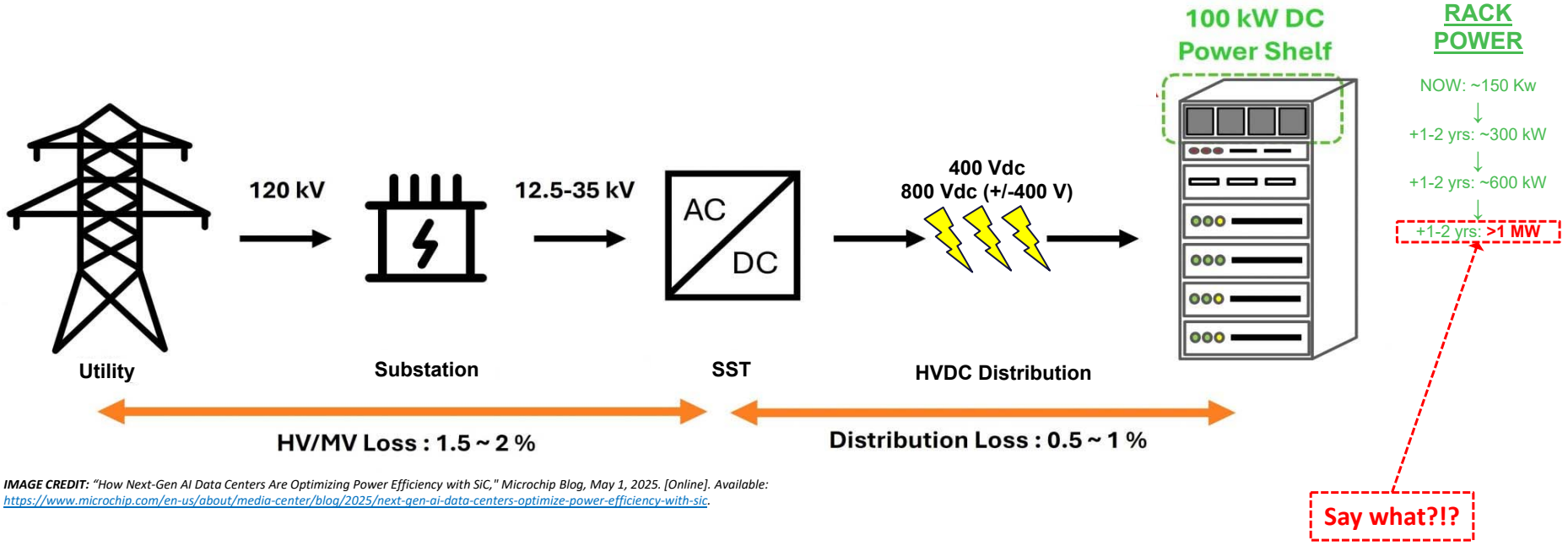
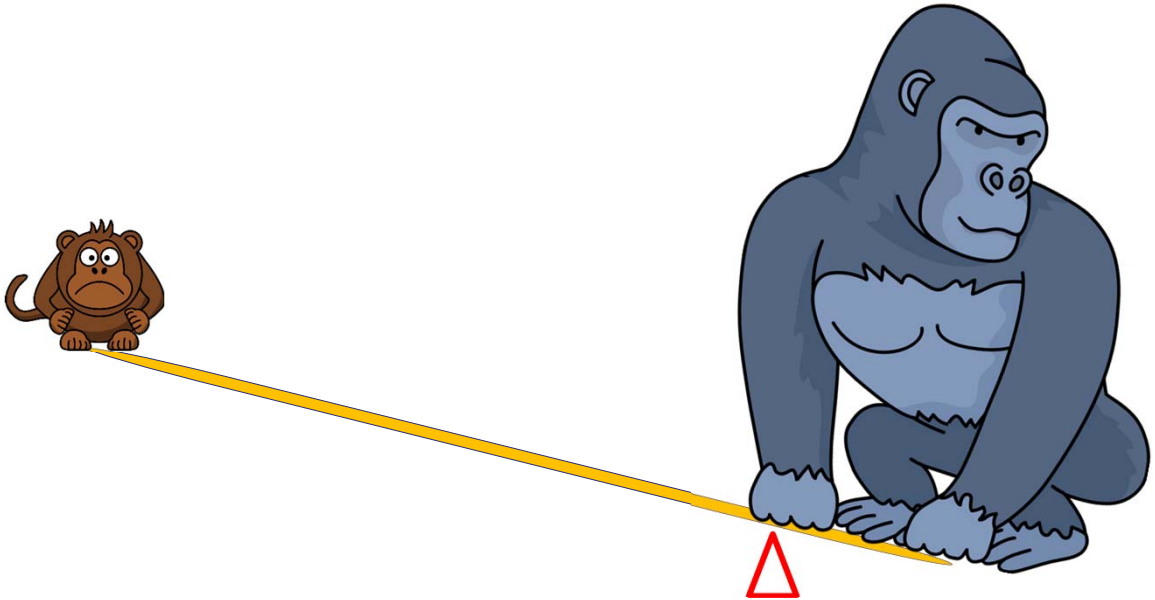


IMAGE CREDIT: *"How Next-Gen AI Data Centers Are Optimizing Power Efficiency with SiC," Microchip Blog, May 1, 2025. [Online]. Available: https://www.microchip.com/en-us/about/media-center/blog/2025/next-gen-ai-data-centers-optimize-power-efficiency-with-sic.*

Massive Loads, Massive Transients

- **What happens when a massive load has a major transient on a grid shared by (relatively) tiny loads?**
  - Even Voluntary Islanding Very Risky



Massive Loads, Massive Transients

- **What happens when a massive load has a major transient on a grid shared by (relatively) tiny loads?**
  - Load So Massive It Eclipses Existing ***STATE*** Peak Load
  - Synchronous Machines Too Slow For Recovery

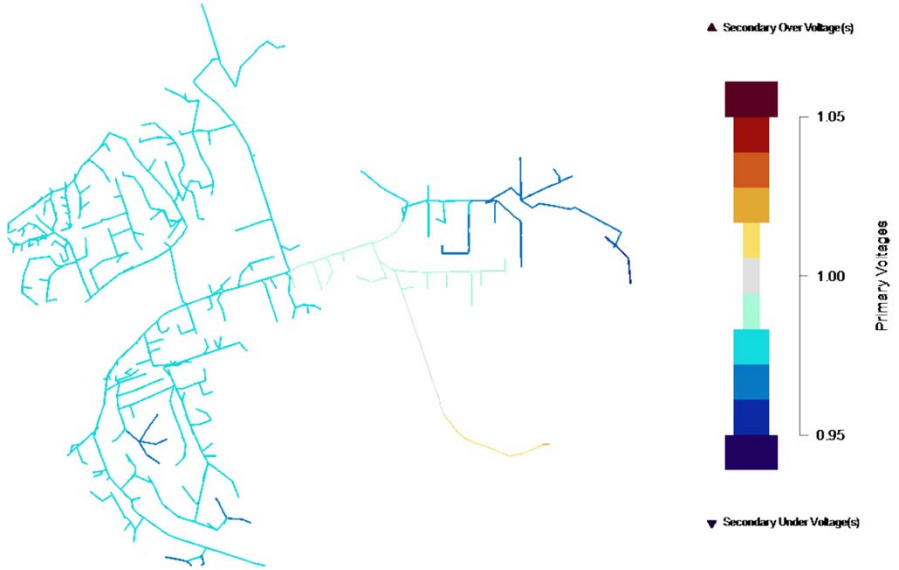


IMAGE CREDIT: *Nagarajan, Adarsh, et al. "Value Streams from Distribution Grid Support Using Utility-Scale Vanadium Redox Flow Battery: NREL-Sumitomo Electric Battery Demonstration Project." , Aug. 2018. https://doi.org/10.2172/1464729.*

Massive Loads, Massive Transients

R_x Things to Keep In Mind

- AI Is Unique as a Load or a Tool
- Not All AI the Same
  - Large Language Model (LLM) Vs. Inferencing/Agentic
- Beyond Virtual Power Plants (VPP)
- Massive Loads Are Reactive
- So Are the Massive Interconnects
- Energy Storage Systems (ESS) Are Your Best Friend (& Enemy)
  - Peak Shaving, Dynamic Load Allocation, Negative Z
  - Short-circuit/Fault Risk, Embodied Footprint/Sustainability
- The Data Center "Power Space Race" Is Driving Improvement in Intelligent Power Management (IPM)
  - Bidirectional Data & Power Flow Are Critical

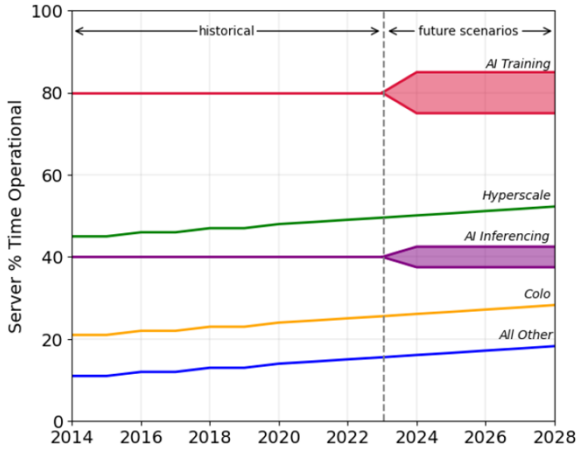


IMAGE CREDIT: *Shehabi, A., Smith, S.J., Hubbard, A., Newkirk, A., Lei, N., Siddik, M.A.B., Holecek, B., Koomey, J., Masanet, E., Sartor, D. 2024. 2024 United States Data Center Energy Usage Report. Lawrence Berkeley National Laboratory, Berkeley, California. LBNL-2001637.*

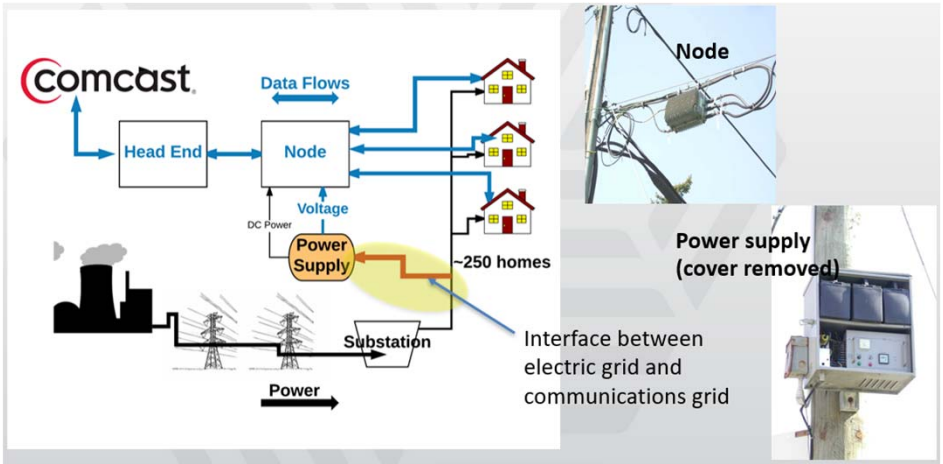
Nexus of Utilities & Data Centers

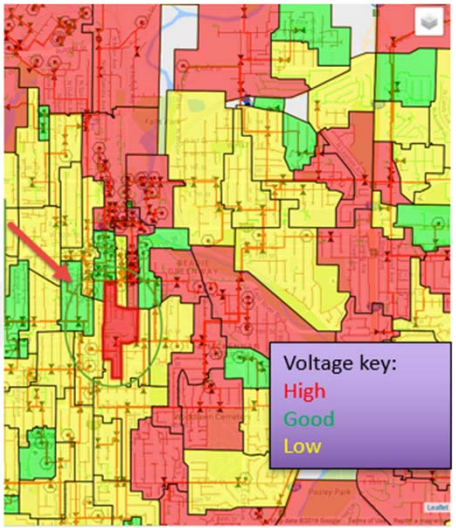
- **Rx Need to Breakdown the ROI Silos**
  - – Everyone Wins Together
- **Rx Modularity & Scalability**
  - – All About Reaction & TTM
  - – GPUaaS / DCaaS
- **Rx Aggregation Vs. Disaggregation**
  - – Integration Enables Better/Faster Telemetry
- **Rx Demand/Fault Response**
  - – Reaction Time
  - – Fault Currents / Blast Radius Containment
- **Rx Scenario Must Be Bad When Data Center Owners BECOMING the Utility**
  - – Most Risk-averse Organizations Investing Billions
  - – Recommissioning / Small Modular Reactors (SMR)

Nexus of Utilities & Data Centers

R_x Existing, Ubiquitous, Low-level Utility Sensor Networks

- Leveraging Motivation & Investment
- CableLabs





Mock-up of display showing node-level voltages updated every 15 minutes

IMAGES CREDIT: *Meier, Alan, "Neighborhood Sensing of Grid Conditions," Lawrence Berkeley National Laboratory, September 2017.*

Nexus of Academia, Industry, & Government

R_x Critical Collaborative Needs

- Development
- CHARACTERIZATION
- Standards
- Sensible (Common) Policy

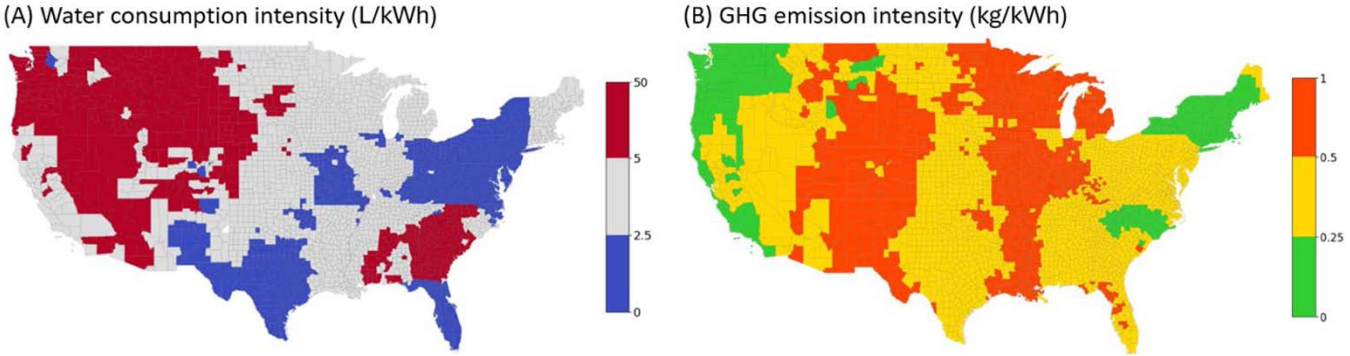
R_x Workforce Development

- Need New Classes of Multidisciplinary Experts
- Especially for Dc-based Data Center Solutions

Nexus of Academia, Industry, & Government

R_x Hierarchical Sacrifice

- Load
- Data Center
- Grid Stability
- Consumers
- Economics



Water consumption and GHG emission intensity factors of electricity use by county.

IMAGE CREDIT: *Shehabi, A., Smith, S.J., Hubbard, A., Newkirk, A., Lei, N., Siddik, M.A.B., Holecek, B., Koomey, J., Masanet, E., Sartor, D. 2024. 2024 United States Data Center Energy Usage Report. Lawrence Berkeley National Laboratory, Berkeley, California. LBNL-2001637.*

Tremendous Opportunities

R_x It Is Time for Power to Shine

- We Are Finally More Than an “Inconvenient Truth” or “Necessary Evil”
- Attention & Investment in AI Enables Us To Accelerate an Energy-efficient/resilient Future
- Profit Is Measured In Power

R_x Motivation to Build Truly Smart Grids

- Bidirectional Intelligence/Optimization Unlocks Power
  - “Packetizing the Power Grid”

M. Almassalkhi, J. Frolik and P. Hines, "Packetizing the Power Grid: The rules of the Internet can also Balance Electricity Supply and Demand," in IEEE Spectrum, vol. 59, no. 2, pp. 42-47, February 2022, doi: 10.1109/MSPEC.2022.9706403.

- Applying AI to AI

Chen, Y., et al. "Artificial Intelligence/Machine Learning Technology in Power System Applications," Pacific Northwest National Laboratory. Mar. 2024. DOI: 10.2172/2340760.

- Microgrids/ESS Can Mitigate the Energy Gap (Sustainably!!)
- A Grid with Balls
  - Claim 40% Savings with IPM

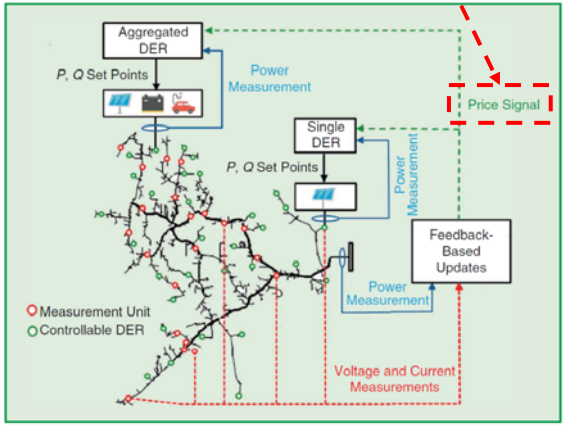
IMAGE CREDIT: *Poor, Alfred, "Smart Powerline ‘Neurons’ Boost Grid Capacity." IEEE Spectrum, Jun 12, 2024. [Online]. Available: https://spectrum.ieee.org/power-line-sensors-smart-grid.*

Tremendous Opportunities

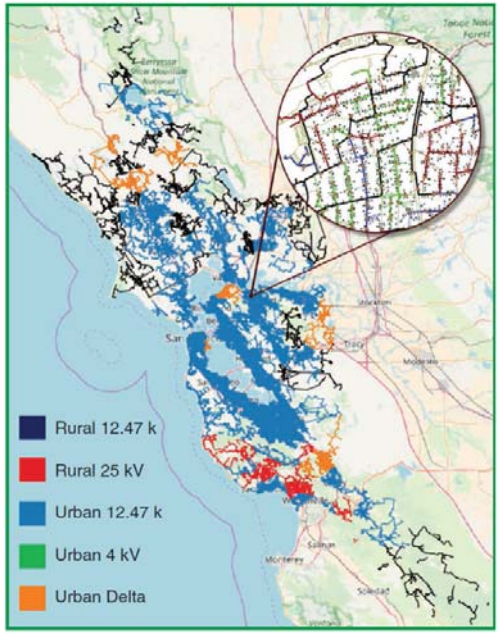
R_x How far can we take it?

- A Look to the Future
  - IIoT-Driven
    - **REALLY** Smart Grid

NOTE: Real-time pricing???

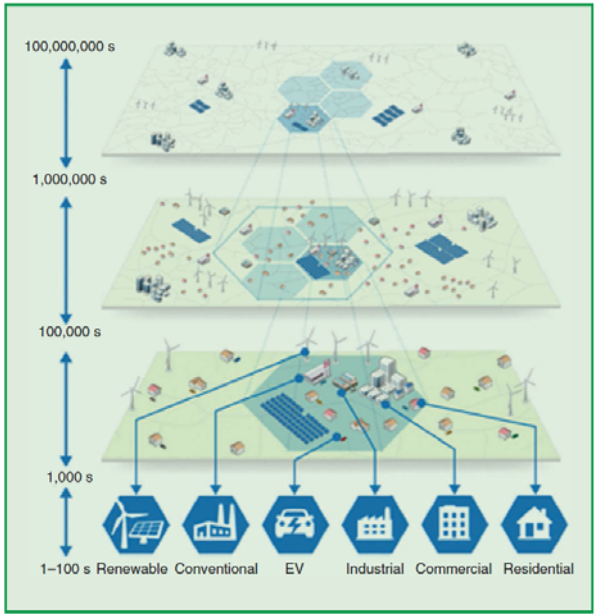


These measurements are used as a feedback mechanism for DER control.
Real (P) and reactive (Q) power are used to optimize conditions on the distribution circuit.



This is the San Francisco Bay Area synthetic distribution system, developed under the ARPA-E GRID DATA program. Line configurations are mostly wye with a small amount of delta. (Source: grid data: NREL; map: OpenStreetMap.org.)

IMAGES CREDIT: *B. Kroposki et al., "Autonomous Energy Grids: Controlling the Future Grid With Large Amounts of Distributed Energy Resources," in IEEE Power and Energy Magazine, vol. 18, no. 6, pp. 37-46, Nov.-Dec. 2020, doi: 10.1109/MPE.2020.3014540.*



The AEGs form a distributed hierarchical control system that integrates individual technologies in a cellular structure to the bulk power system. The scale on the side indicates the number of controllable technologies seen along the bottom level. The lowest level depicts the locations of various generation, storage, and loads.

Tremendous Opportunities

R_x Dc Opens the Floodgates

- Current Alone Not Going to Keep Up
- Microgrid & ESS Assets Intrinsically Dc
- Integration Yields Density, Reliability, Serviceability, & $$$

R_x Solid-state Solutions

- Need for speed? ***OR*** Such a thing as too fast?
- All or nothing?

Tremendous Opportunities

R_x Taking Another Look at Energy Harvesting

- Tiny Power Enables Mega Power Impact
- Nothing Better Than 100 % Conversion Efficiency

> *"There is no such thing as **waste heat**…just underutilized **energy recycling opportunities**."*
>
> – Brian Zahnstecher

R_x Getting Creative with Energy Storage

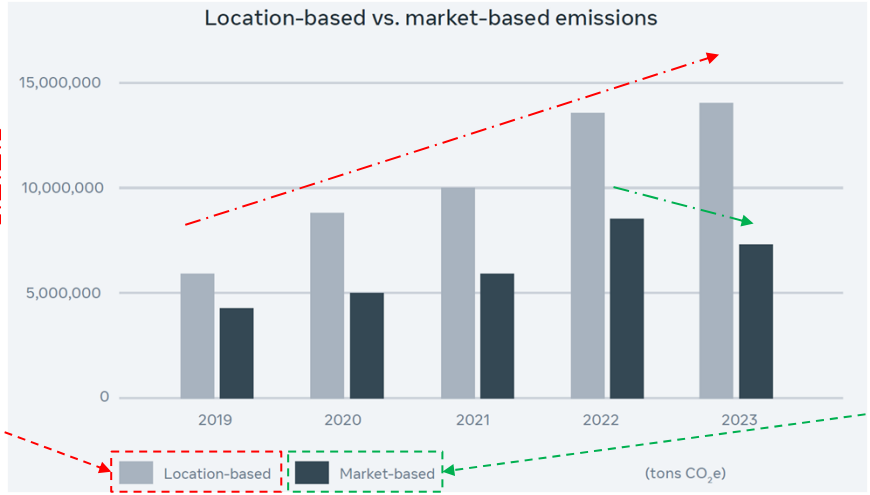
- Implement At All Levels
- Hybrid Solutions Optimized for Performance ***OR*** Cost
- Utilize For Technical & Economical Purposes

BONUS: SOAPBOX MOMENT!

R_x Sustainability Reports

– Can Be Great Consolidation of Data/Lessons/Best Practices
– Watch the bias!! (e.g. – greenwashing)
– What are the latest trends? (i.e. – recent reports from all the hyperscalers)

- YoY Increase
- Actual Emissions ONLY Increase



- YoY Decrease Based on RECs
- Accounts for HALF of Actual Emissions

Location-based
(e.g. – ACTUAL footprint)

Market-based
(e.g. – greenwashed)

IMAGE CREDIT: *"2024 Sustainability Report," Meta, August 2024.*

Summary & Conclusions

- **Very large, high-transient loads can be used to solve problems, not just create them.**
  - Implement Bidirectionality, Make Better Choices
- **All Roads Lead to Dc**
- **AI can be viewed as the ultimate load and/or tool…**
  - …but do not forget everyone else!
- **We all know major grid revamp is necessary, but that does not mean existing structure cannot be utilized in more intelligent ways.**
  - Siloed Approaches Will Fail
- **Need improved characterization of loads and fault response.**
- **AI must be deployed with equitable grid usage in mind.**
- **Sustainability always in mind…watch out for greenwashing!**

Q & A

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Thanks a lot for your time and attention!

Any questions and/or comments?

"How thoughtlessly we dissipate our energies
Perhaps we'll help fulfill each other's fantasies
And as we stand upon the ledges of our lives with
our respective similarities
It's either sadness or euphoria"
– Billy Joel, Summer, Highland Falls

References

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