Microgrids for Military Installations:
A Technology Review

ALI MEHRIZI-SANI

ASSOCIATE PROFESSOR

Resilient Renewable Energy Grid Adaptation Laboratory (REGAL)

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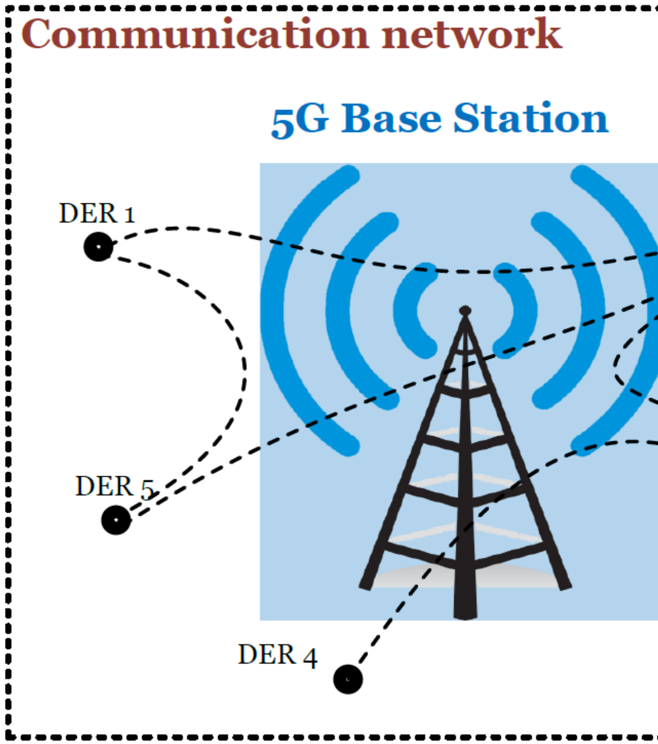
Americas Session



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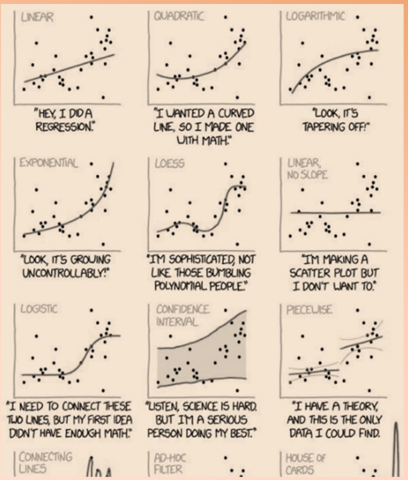
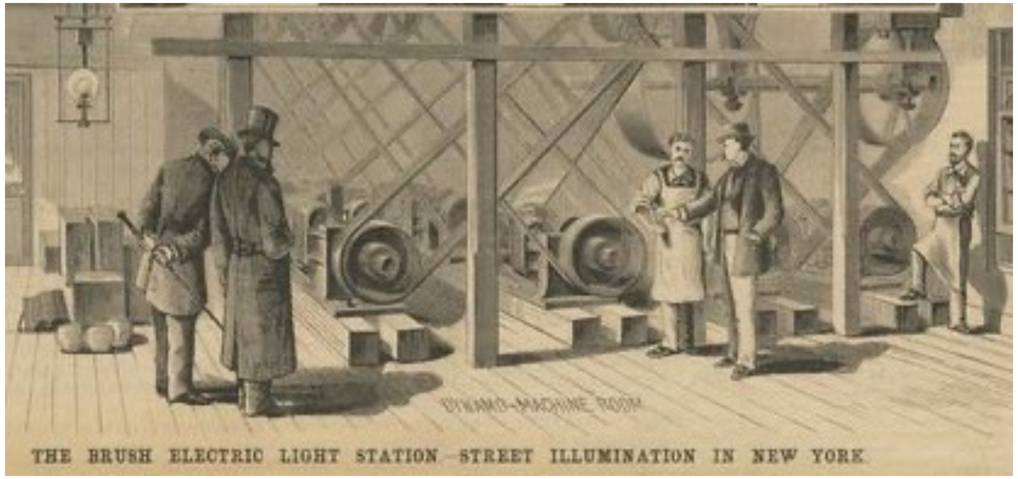
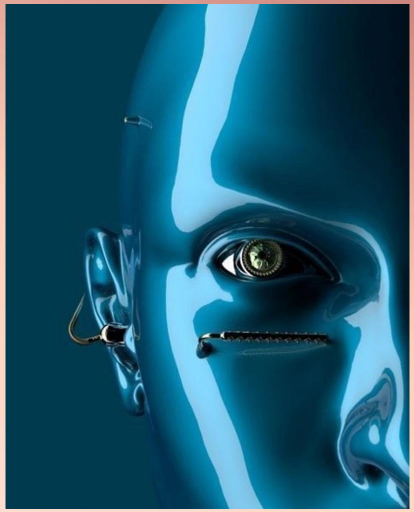
New Capabilities, New Horizons, New Challenges

Renewables | Machine Learning | Communications | Power System







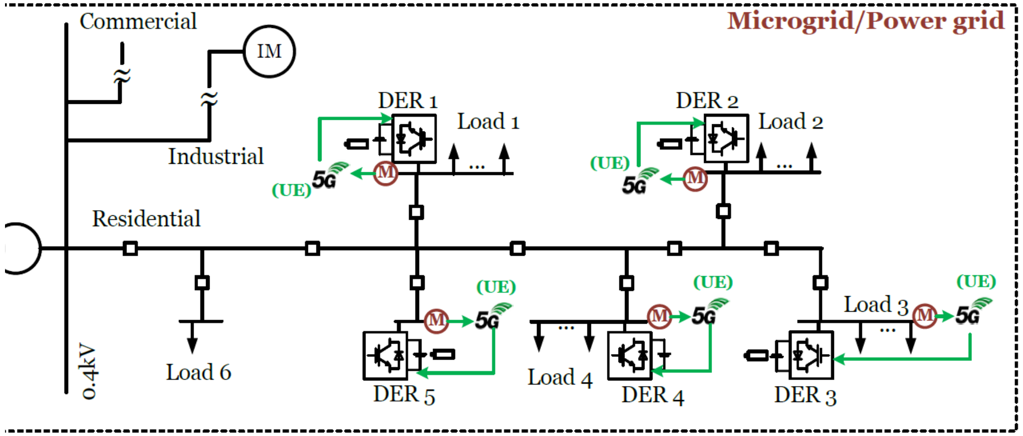


Image Credit: Wikipedia; Pinterest; https://www.survivopedia.com/4-effortless-steps-to-make-your-own-smoke-signal-flares/; https://www.nai-group.com/what-is-5g-technology/

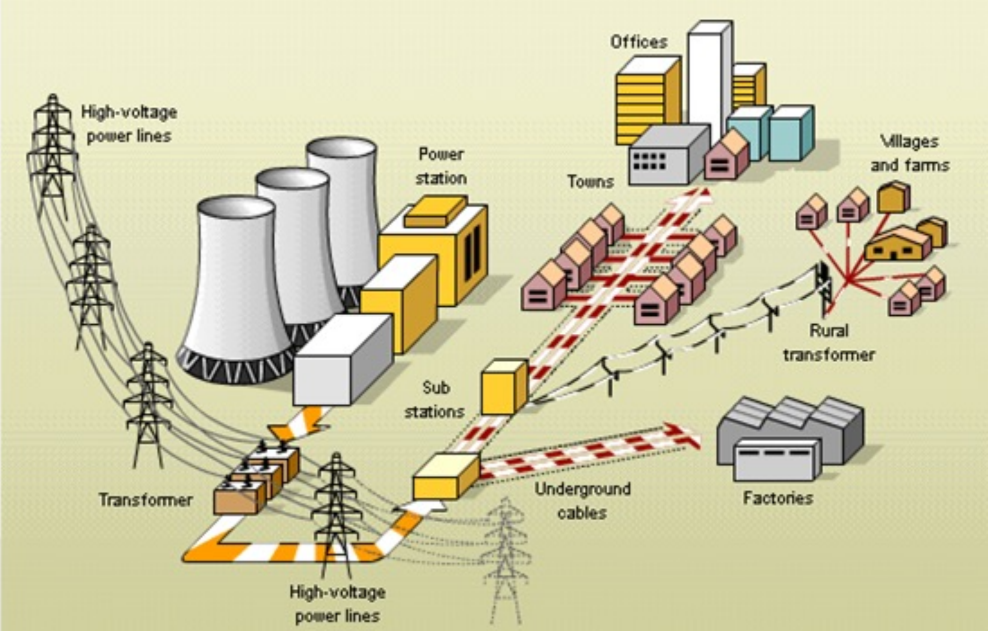
An "Old" Term: Smart Grid

- Definition by National Institute of Standards and Technology (NIST)
  - "A modernized grid that enables bidirectional flows of energy and uses **two-way communication** and control capabilities that will lead to an array of new functionalities and applications."
- Bidirectional flow of energy: Distributed/renewable energy resources
- Bidirectional flow of data: A pervasive communication network

Technology	Standards	Data rate[a]	Distance covered	Latency	Cost
ZigBee	IEEE 802.15.4	Low	100 m	50 ms	Low
WLAN	IEEE 802.11ax	Very high	70 m	3 ms	Medium
	IEEE 802.11ac	High	70 m	10 ms	Low
	IEEE 802.11n	Medium	50 m	15 ms	Low
	IEEE 802.11g	Medium	50 m	15 ms	Low
Cellular	2G	Low	35 km	300 ms	Low
	3G	High		100 ms	Low
	4G	High		10 ms	Low
	5G	Very high		<1 ms	Medium
WiMAX	IEEE 802.16	Medium	30 km	50 ms	High
PLC	\	High	1–5 km	5 ms	Medium
Fiber-optic	\	Very high	>100 km	3 μs/km	High

[a]Data rate: low (<1 Mbps), medium (1–100 Mbps), high (100 Mbps-1 Gbps), and very high (>1 Gbps).

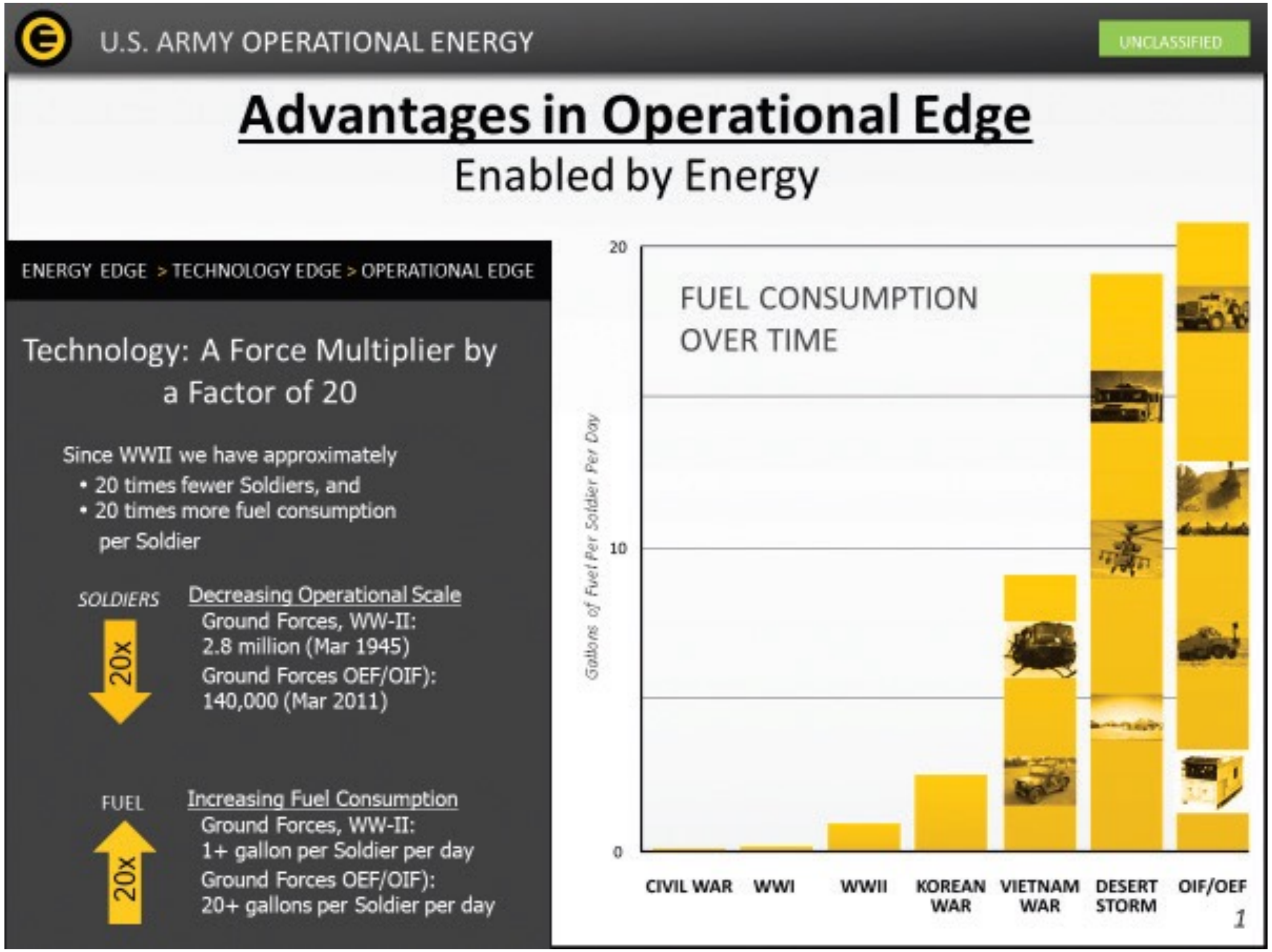
Comparison of Typical Communication Technologies for a smart grid [Liu et al. 2021]



Use Case: U.S. Army's Energy Use Trend

- Our modern society depends on energy.

- About 1/3rd of the energy consumed in the U.S. industrial, commercial, and residential sectors is in the form of electrical energy.



Advantages in operational edge. SOURCE: R. Kidd, U.S. Army, 2012, "Army Energy and Sustainability Program," presentation, https://www.asaie.army.mil/Public/ES/doc/2-General%20Presentation.pdf accessed through National Academies of Sciences, Engineering, and Medicine 2021. Powering the U.S. Army of the Future. Washington, DC: The National Academies Press. https://doi.org/10.17226/26052

Current State of Installation Power Systems

- (Domestic) installations are connected to the grid most of the time, but when grid is out, some facilities can have backup power for a limited time through local, individual generation.

- Quality of the grid can impact services within the installation.

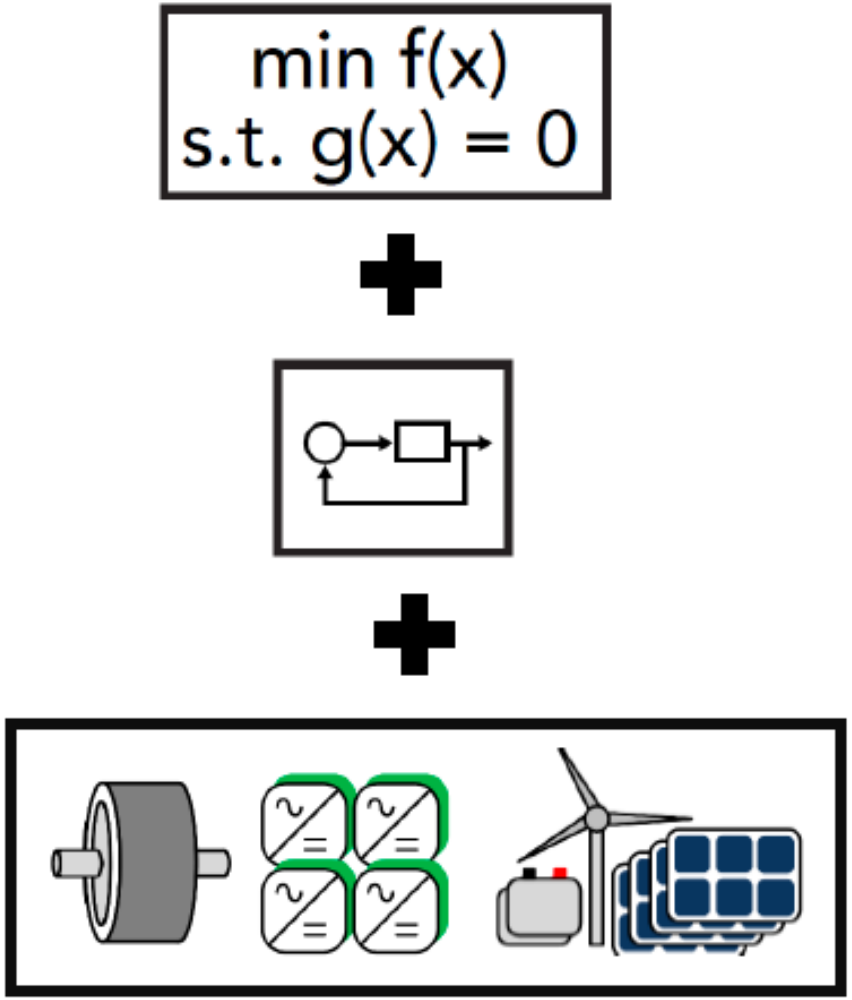
- Availability of power is impacted by fuel supply chain vulnerabilities.

Grid

- *Grid* is the informal term used for the formally defined *bulk power system:*
  - "facilities and control systems necessary for operating an interconnected electric energy transmission network (or any portion thereof)."

  (Federal Power Act, 16 U.S.C. §824. 1920)

- One of the 20 greatest engineering achievements of the 21st century as selected by the US National Academy of Engineering.



Vulnerabilities of the Power Grid: Maxima Machina

- Grid is geographically expansive (and exposed).

WEATHER; RESILIENCY.

Weather-related power outages cost the United States $18-$33 billion every year. An average of 700,000 consumers are impacted during each weather-induced power outage annually.

PHYSICAL SECURITY.

A 2013 sniper attack on a PG&E substation near Silicon Valley disabled 17 transformers and cost PG&E approximately $100 million. Repairs took 27 days.

- These directly translate into vulnerabilities of the installations.

https://www.idealenergysolar.com/building-energy-resiliency-for-the-military-with-microgrids

Vulnerabilities of the Power Grid: Maxima Machina

CYBERSECURITY.

In 2015, the insurance underwriter Lloyd's developed a scenario for an attack on part of the Eastern Interconnection, which provides power to around half of the U.S. Under the scenario, an attack targeting power generators would cause a blackout in 15 states and the District of Columbia, leaving 93 million people without power. Only 10% of the generators targeted in this attack would need to be taken offline in order for it to succeed.

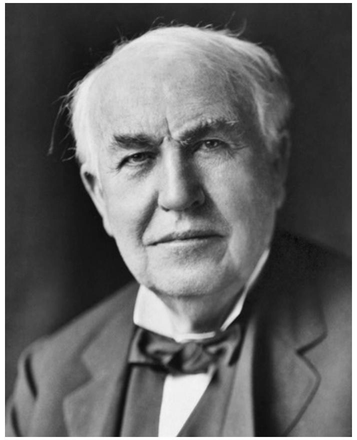
FOSSIL FUELS.

Fossil fuels are directly contributing to grid vulnerability. One recent example is the Texas winter freeze in 2020, in which major points of failure in the natural gas fuel supply left more than 4.5 million customers–or an estimated 10 million people–without electricity. In military settings, there are also logistical issues, e.g., vulnerability of the convoy.

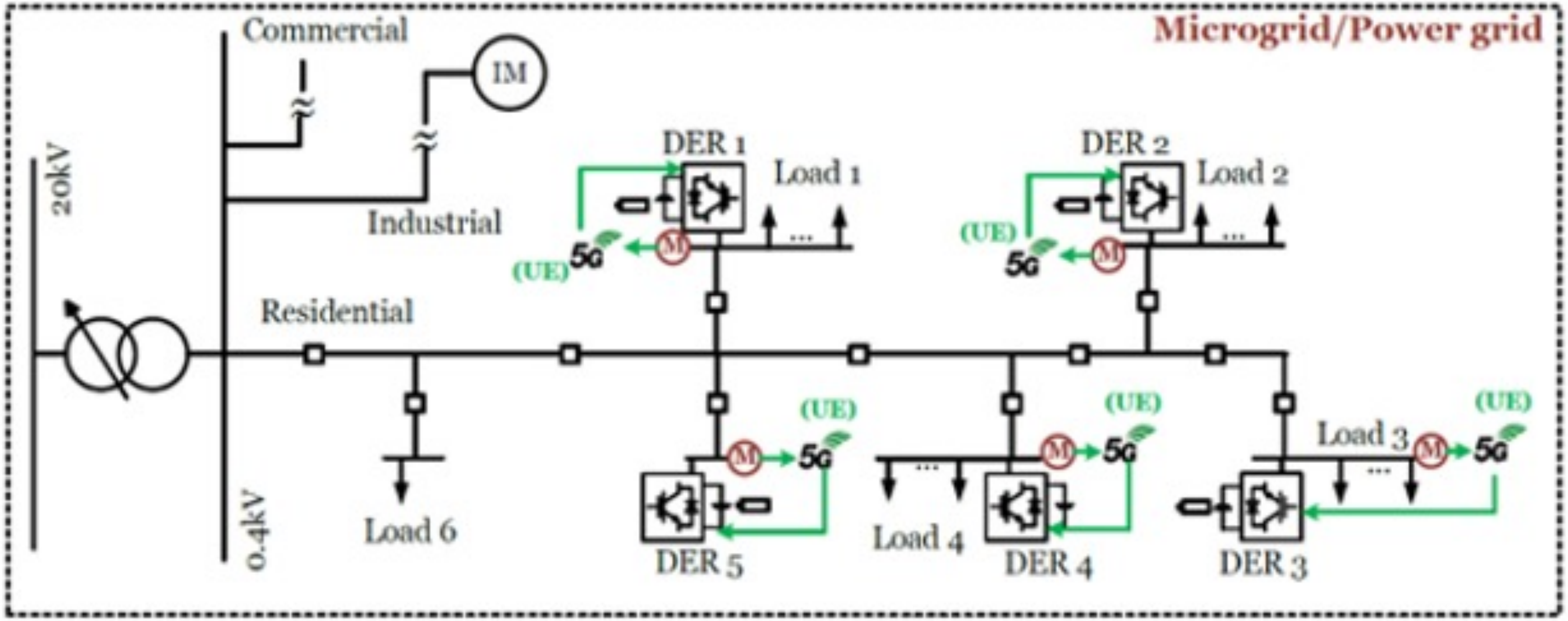
https://www.rpc.senate.gov/policy-papers/infrastructure-cybersecurity-the-us-electric-grid

Proposed Solution: xG-Based Installation Microgrids

- What is a microgrid and how xG can help?
- Microgrid is (Definition by the U.S. Department of Energy)
  - A complete but miniature power system that is an aggregate of collocated resources (loads, generation units, and storage units, or DER: distributed energy resources) that are interfaced to the main grid at the distribution level through a point of common coupling (PCC) and can operate in the grid-connected and islanded modes.



The power system in the Edison's time was effectively a collection of (DC) microgrids–each with its own set of loads and generators.



Philadelphia's The Navy Yard: GridSTAR Microgrid

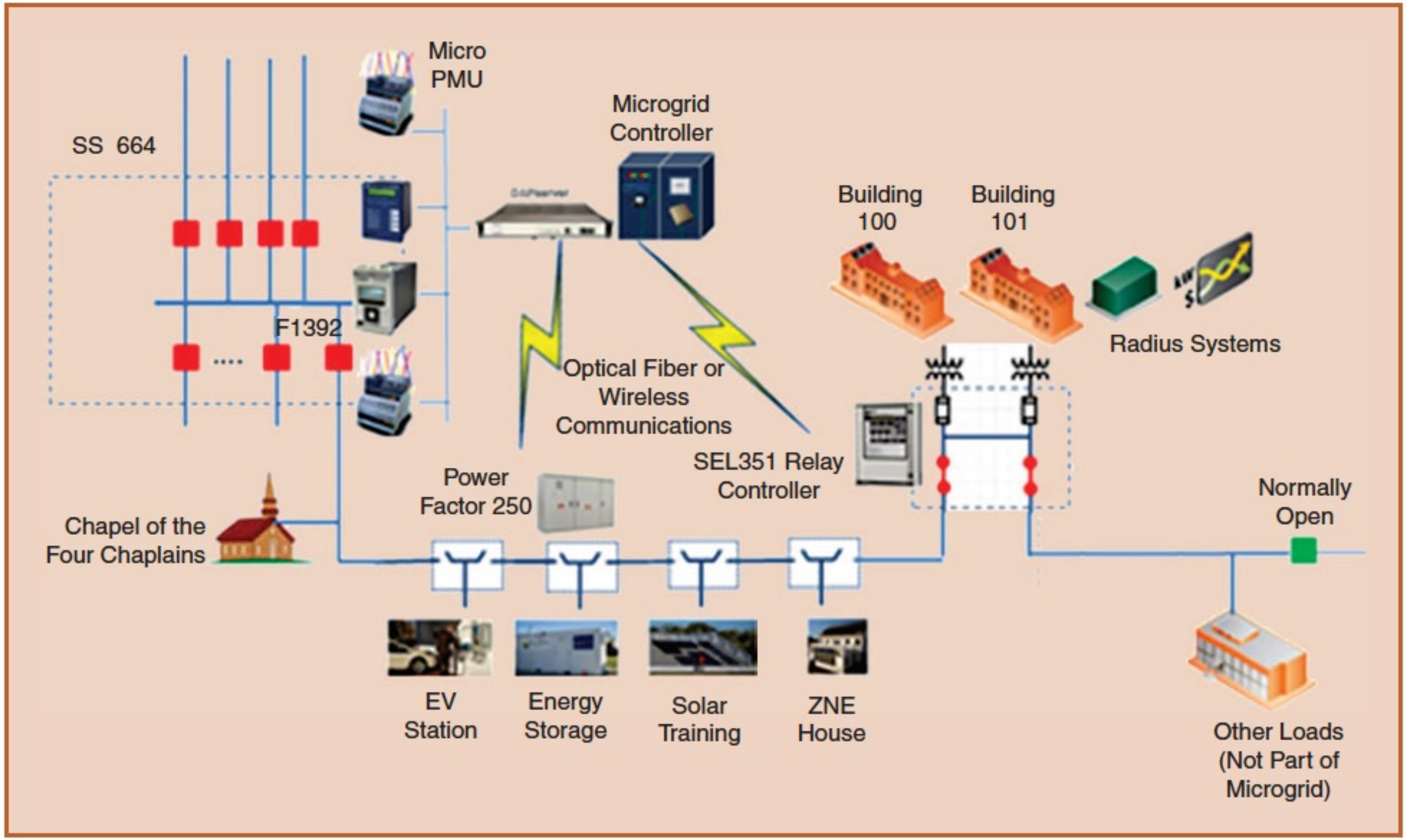


table 1. A summary of loads on GridSTAR microgrid.

Microgrid Assets and Load	Microgrid System	Load (kW) Average Demand	Load (kW) Controllable Load
ZNE House	GridSTAR	4	2
Electric vehicle charging	GridSTAR	10	10
Solar grid storage (RT efficiency)	GridSTAR	20	20
Building 101	GridSTAR	150	75
Building 100	GridSTAR	160	50
Chapel	GridSTAR	16	0
Total		360	187

R. Uluski, J. Kumar, S. S. M. Venkata, D. Vishwakarma, K. Schneider, A. Mehrizi-Sani, R. Terry, and W. Agate, "Microgrid controller design, implementation and deployment–Experiences at The Navy Yard Community at Philadelphia: A journey from conception to implementation," *IEEE Power and Energy Magazine*, vol. 15, no. 4, pp. 50-62, Jul./Aug. 2017.

Microgrids in the US Military: An Emerging Trend

Feb. 2022: Army will build a microgrid at its 130 bases worldwide by 2035.

"The effects of climate change have taken a toll on supply chains, damaged our infrastructure, and increased risks to Army soldiers and families due to natural disasters and extreme weather," said Army Secretary Christine Wormuth.

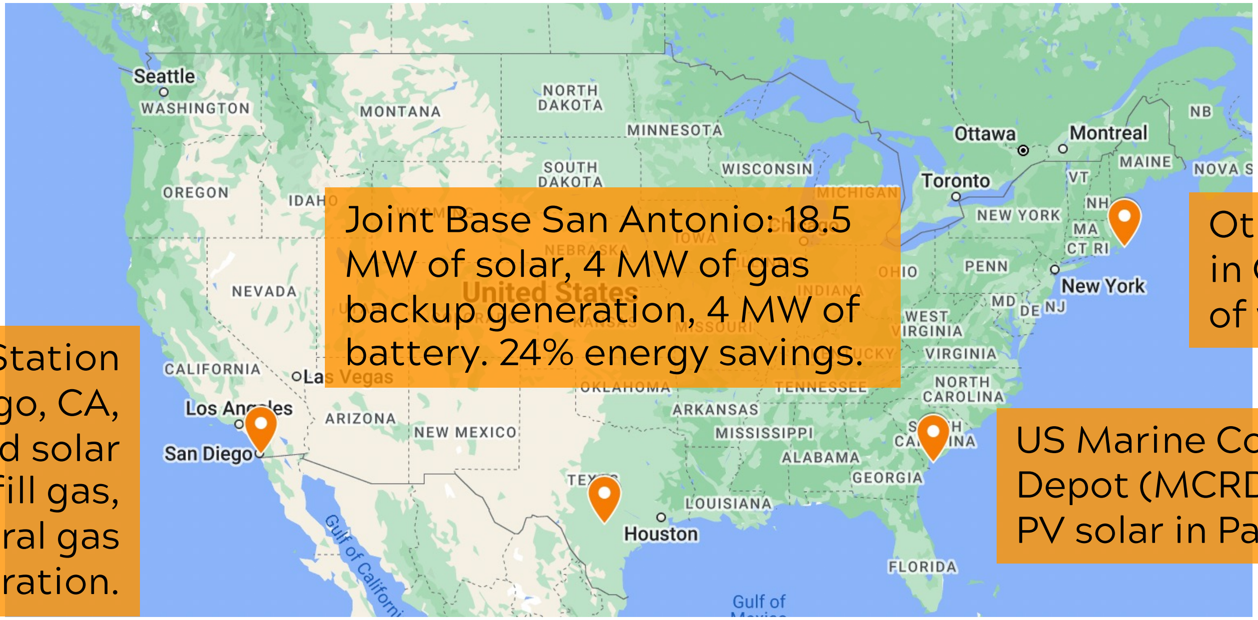
May 2022: Navy will build cybersecure microgrids to protect from disasters while decarbonizing its energy supply.

Nov. 2021: Air Force is leasing for a solar microgrid system at Tyndall Air Force Base. The AFB was damaged during Hurricane Michael in 2018.

References:
https://www.army.mil/e2/downloads/rv7/about/2022_army_climate_strategy.pdf
https://microgridknowledge.com/navy-microgrids-climate-strategy/
https://www.ameresco.com/portfolio-item/joint-base-san-antonio-texas/
https://www.af.mil/News/Article-Display/Article/2837905/air-forces-first-energy-assurance-lease-signed-at-tyndall-afb/

Status Quo: Bases Across the Nation

- Bases today do operate microgrids…



Marine Corps Air Station Miramar in San Diego, CA, with 11 MW of combined solar PV, landfill gas, and diesel/natural gas generation.

Joint Base San Antonio: 18.5 MW of solar, 4 MW of gas backup generation, 4 MW of battery. 24% energy savings.

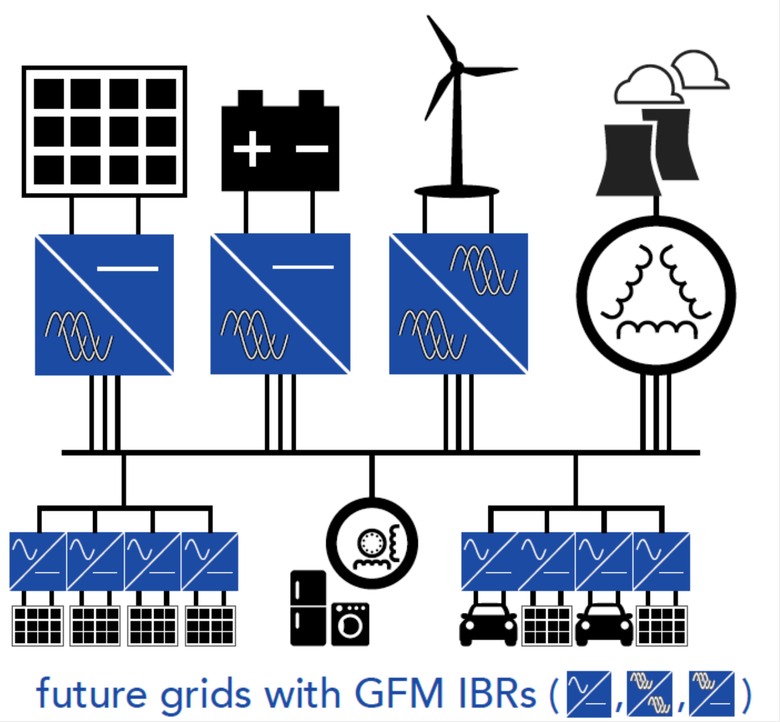
Otis Air National Guard Base in Cape Cod, MA, with 3.1 MW of wind and diesel backup.

US Marine Corps Recruit Depot (MCRD) with 10 MW PV solar in Parris Island, SC.

- And there are bases that do utilize 5G…
  - Examples: Hill Air Force Base near Ogden, UT, and Albany, GA.
  - DoD is prototyping and evaluating 5G technologies at 12 bases in the nation.
- However, most of these bases do not focus on 5G deployment for electrical grid applications as a microgrid utilizing renewables. We integrate microgrids and (intelligent) 5G for installations of the future.

But what are the challenges?

- Microgrids have been around for a decade or so.
- Power community has been working on control of renewables and inverter-based resources (IBR) in different modes, including grid-forming converters.

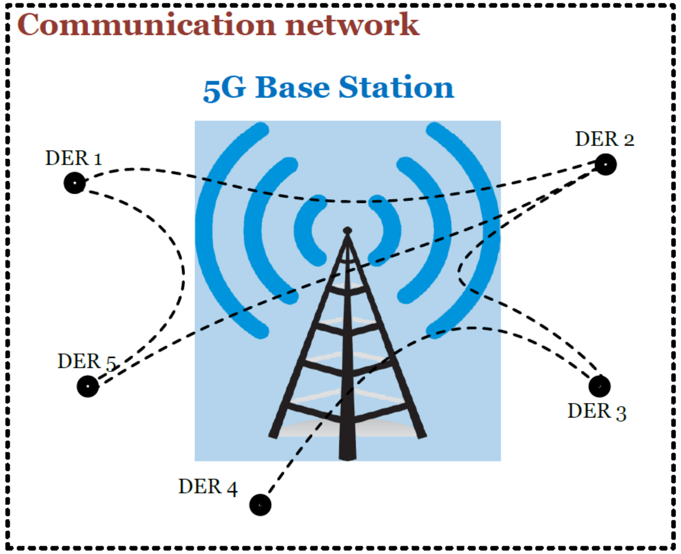


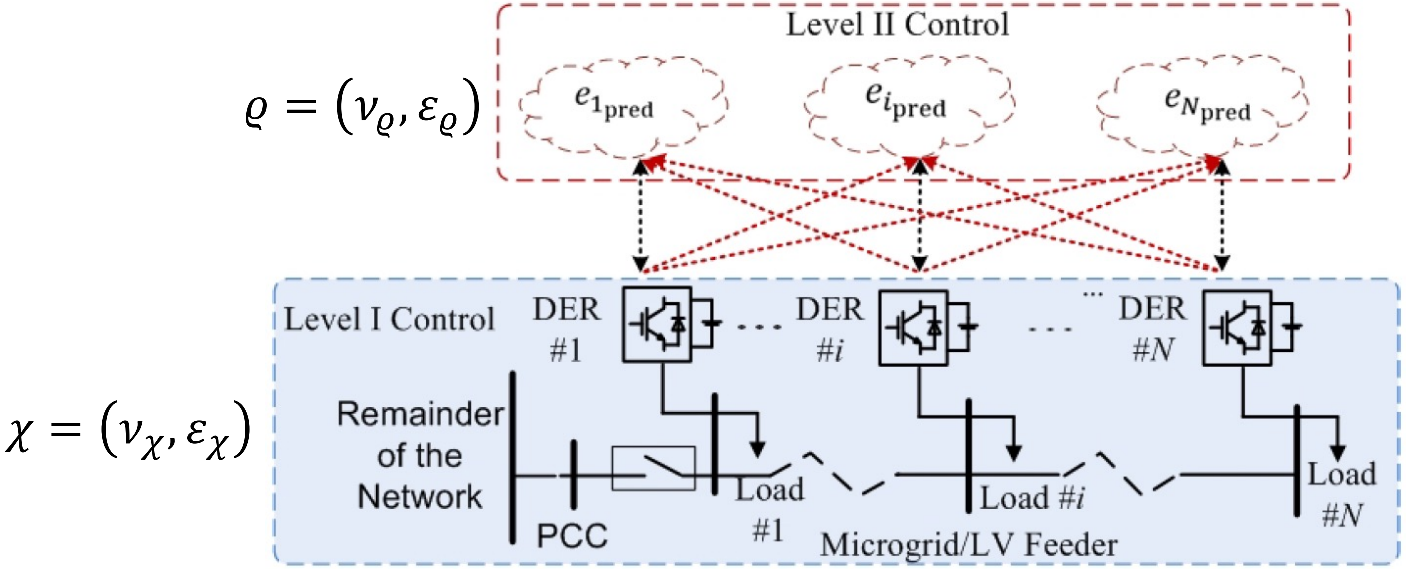
Credit: UNIFI consortium

This Needs (xG) Communication

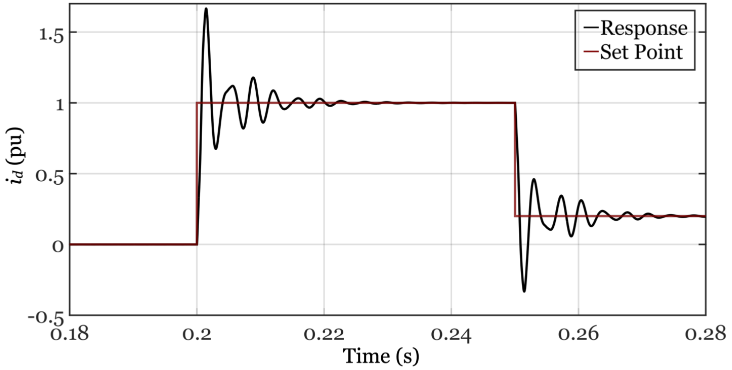
- Further improvement of the performance of these controllers needs them to coordinate with each other.
- But central coordination is not easy to do, different devices and service owners do not trust each other, and processing power is limited.
- That leads us to distributed control, on which the power and control communities have worked for several decades.
- To successfully implement distributed control in the power system, we need also fast communications (our needs typically exceed traditional network capabilities: latency and/or bandwidth and security) and we need it to be secure (i.e., cybersecurity) and resilient (withstanding large events).

Example of 5G-Enabled Control

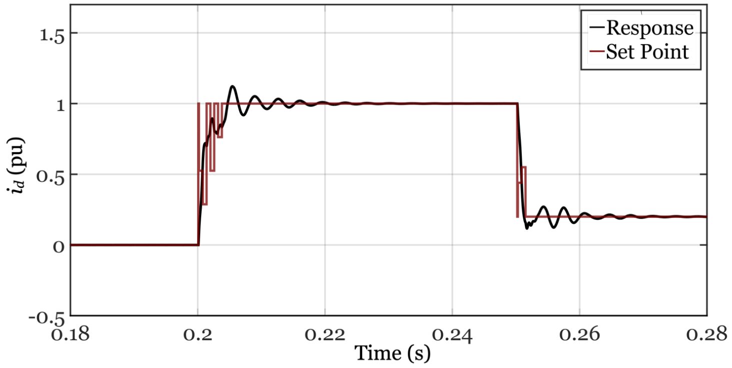




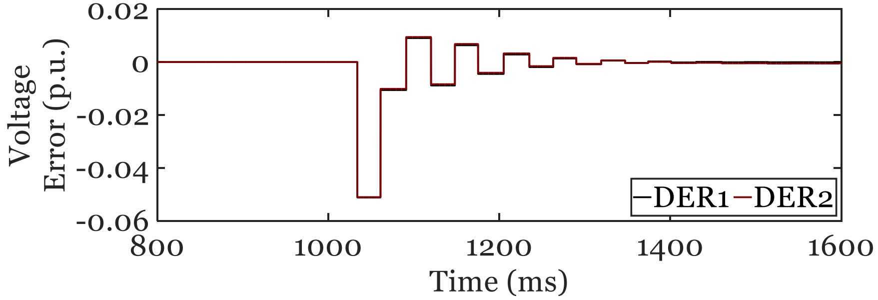
DER Currents without SPAACE



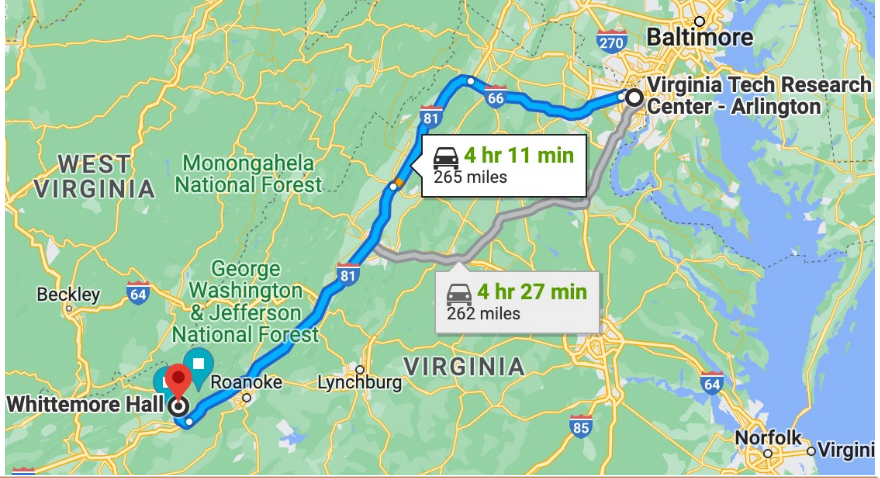
DER Currents with SPAACE

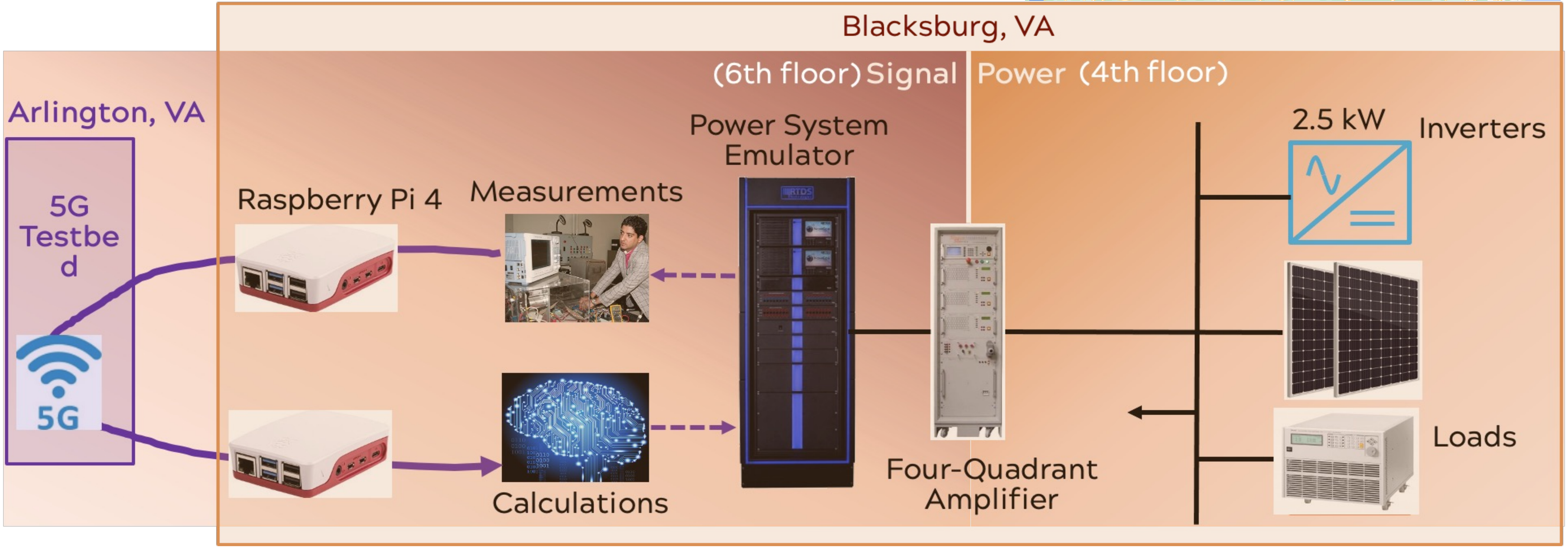


Communicated Error Signals



VT 5GPG Testbed (now xGPG?)





Relevant Resources

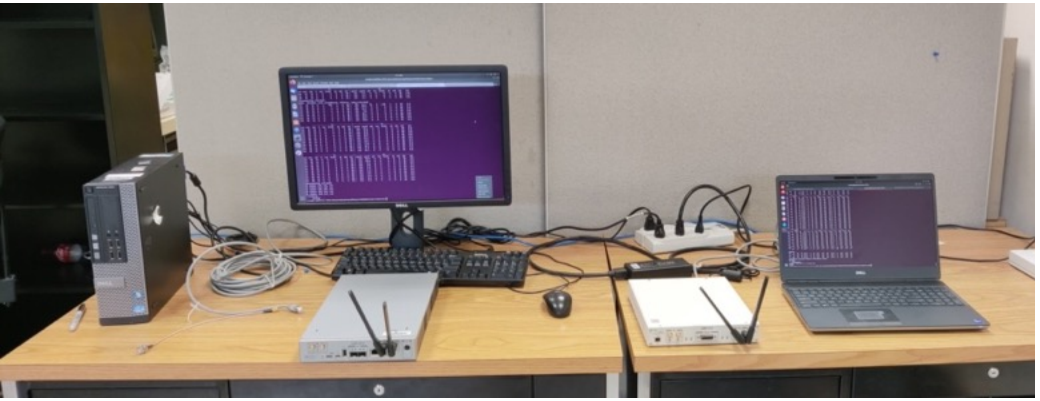


Fig. 1. In-lab 5G O-RAN Testbed at VT and GMU

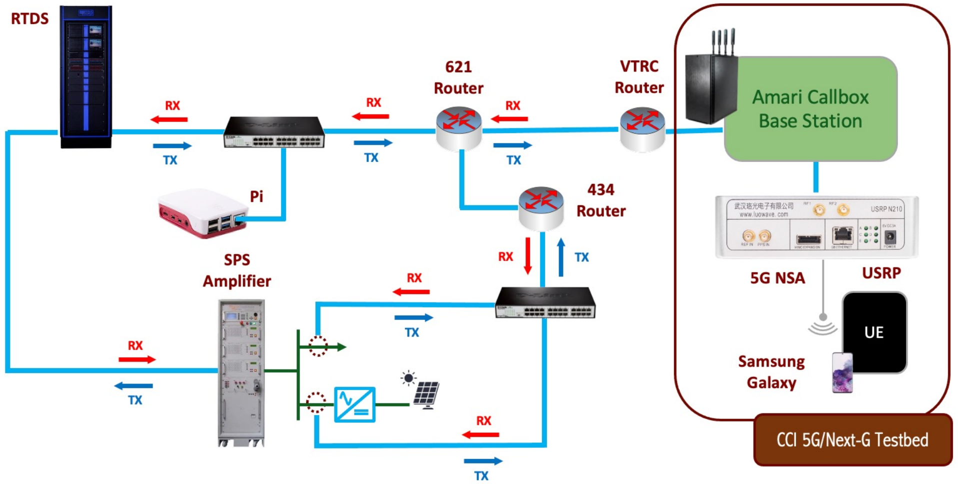


Fig. 3. VT/CCI 5G-microgrid testbed setup

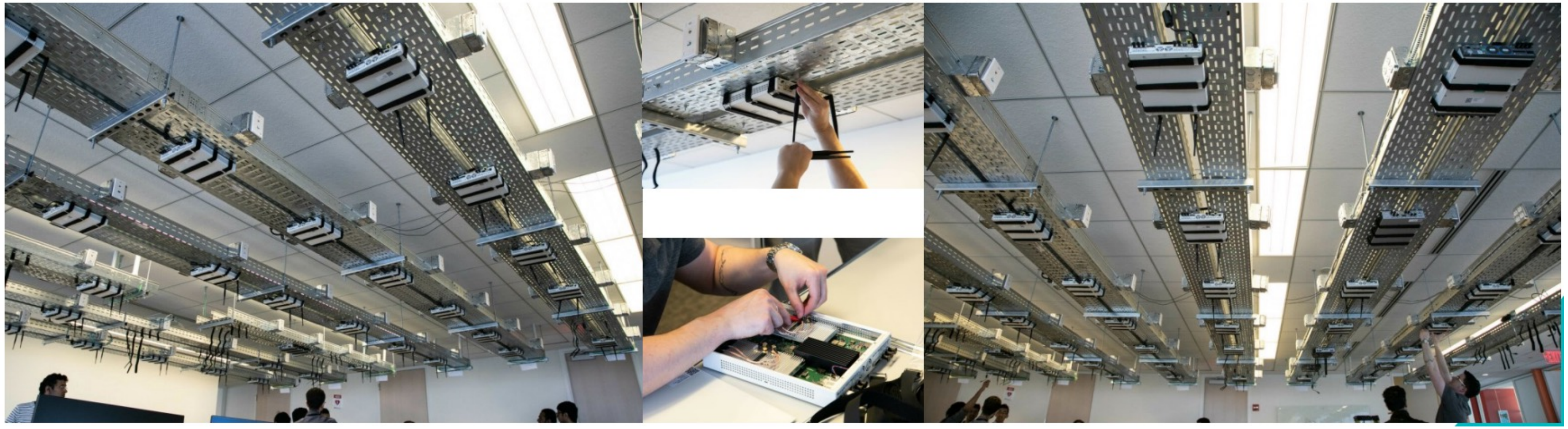


Fig. 2. VT/CCI xG Testbed. With 72 nodes, 4 MEC, and O-RAN capability, this is one of the largest university-based SDR testbed in US.

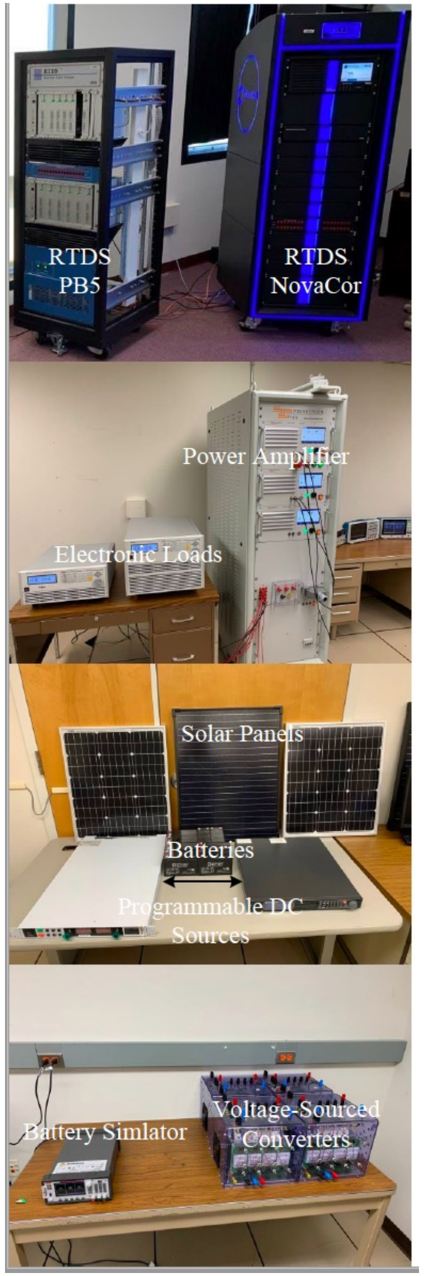


Fig. 4. VT microgrid testbed setup

Recap: Advantages of xG Microgrids

Cost savings
- Both power side and communication side

Green energy
- Address requirements of green renewable energy
- Reduce dependencies on fossil fuels

Grid efficiency
- Address efficiency of grids on generation, transmission, distribution and storage of energy

Security, resiliency, and reliability
- Both cyber and physical attacks
- Disasters

- Example JBSA microgrid:
  - 24% Annual Energy Consumption Reduction, $8.7M Annual Energy Savings, 14.7 M Square Feet Facility Size, $133.5M Task Order Size

https://www.ameresco.com/portfolio-item/joint-base-san-antonio-texas/

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Ali mehrizi-Sani

mehrizi@VT.EDU
mehriziSANI.COM

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