Distributed Energy and Infrastructure Resilience

Society of American Military Engineers

Jim Reilly, Electrical Engineer - Microgrid Deployment

October 12, 2021

REVIEW DRAFT – NOT FOR CITATION, QUOTATION, OR DISTRIBUTION

1. Resilience Definitions
2. Resilience Frameworks and Resilience Valuation
3. Approaches to Resilience
4. Standby Generation, Microgrids, and SmartGrids
5. Resilience Infrastructure O&M Considerations
6. Cyber Security for microgrids and DERs
7. NREL microgrid design process and campus overview
8. Example DOD Microgrids (If there’s time)

Resilience Definitions and Requirements

10 U.S.C. §101(e)(8)

- the capability of a military installation to avoid, prepare for, minimize the effect of, adapt to, and recover **from extreme weather events, or from anticipated or unanticipated changes in environmental conditions**, that do, or have the potential to, adversely affect the military installation or essential transportation, logistical, or other necessary resources outside of the military installation that are necessary in order to maintain, improve, or rapidly reestablish installation mission assurance and mission-essential functions.

Draft FY22 NDAA

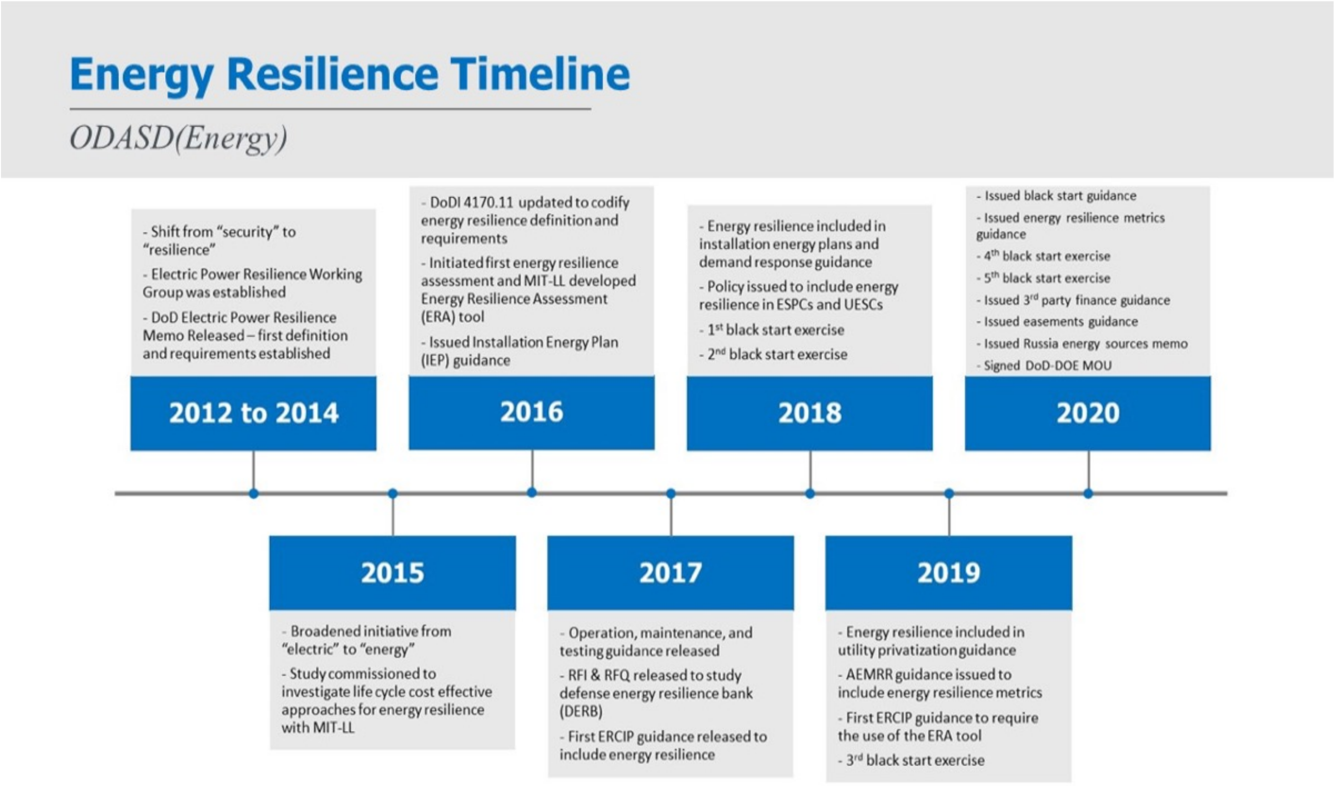
- Section 2482 - The Secretary of Defense shall amend the Unified Facilities Criteria/DoD Building Code (UFC 1-200-01) to require that planning and design for military construction projects inside the United States include consideration of the feasibility and cost-effectiveness of installing an energy microgrid as part of the project, including intentional islanding capability of at least seven consecutive days, for the purpose of ……..

DOD/Branch-level requirements/goals

- Office of the Assistant Secretary of Defense for Sustainment - Energy Resilience Program
  - https://www.acq.osd.mil/eie/ie/fep_energy_resilience.html
- Navy P602 - 3 Pillars of Energy Security (Reliability, Resilience, & Efficiency)
  - https://www.wbdg.org/ffc/navy-navfac/p-publications/p-602
- Army - Office of the Assistant Secretary of the Army for Installations, Energy and Environment - Strategy 2025
  - https://api.army.mil/e2/c/downloads/377960.pdf
- Air Force – Installation Energy Strategic Plan
  - https://www.safie.hq.af.mil/Portals/78/documents/IEE/Energy/AF%20Installation%20Energy%20Strategic%20Plan_15JAN2021.pdf?ver=c0kYPunT7pLBOOxv5bGJaA%3d%3d

Additional Resources

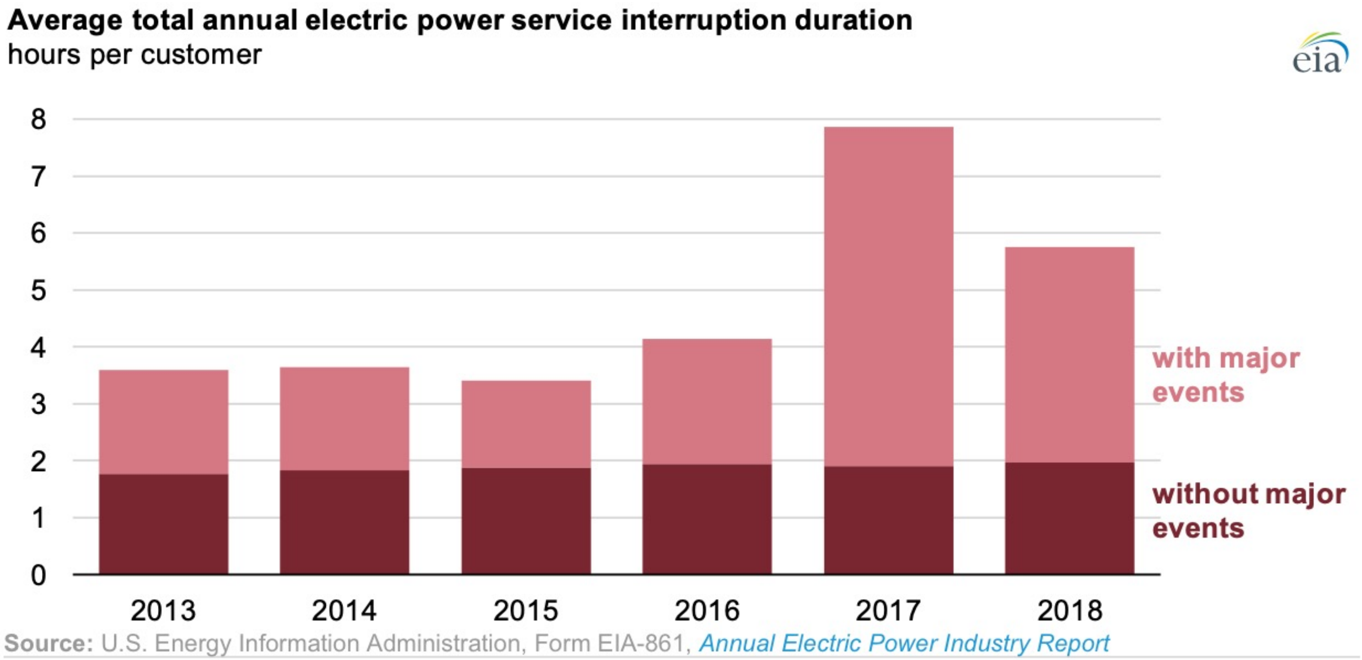
- https://www.energy.gov/sites/prod/files/2017/06/f34/5_Storage%20and%20Microgrids%20Panel%20-%20Ariel%20Castillo%2C%20DoD.pdf
- https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/417011p.pdf



https://www.acq.osd.mil/eie/ie/fep_energy_resilience.html

Jim's thought process when someone says "We Need Energy Resilience"

- **Reliability** – Avoid small outages
  - US electric utilities are experts in this space (average reliability is greater than 99.9%)
- **Resilience** – Operate missions during long duration regional grid outages
  - Questions
    - For how long?
    - What level of downtime during transition is "acceptable"?
    - Is 24/7/365 backup power capability truly needed?
    - Are concerns with on or off installation distribution network?



Source: https://www.eia.gov/todayinenergy/detail.php?id=43915

1 Resilience Definitions

2 **Resilience Frameworks and Resilience Valuation**

3 Approaches to Resilience

4 Standby Generation, Microgrids, and SmartGrids

5 Resilience Infrastructure O&M Considerations

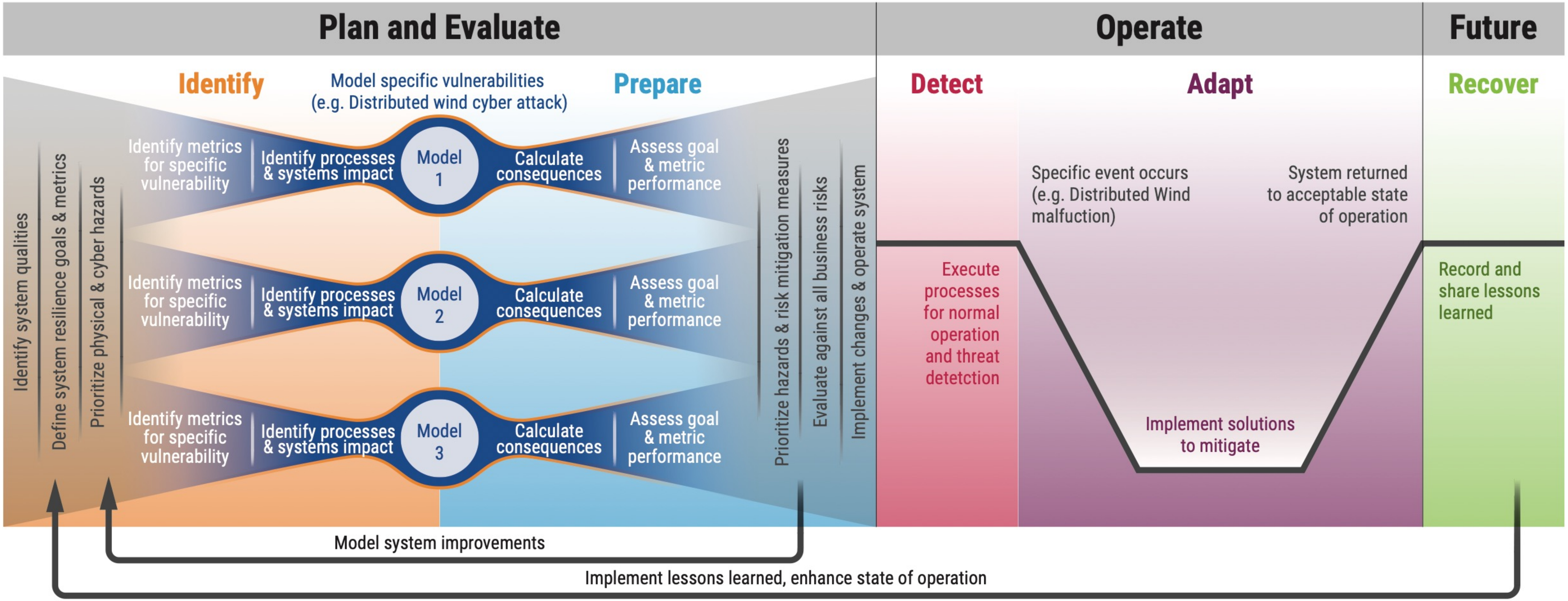
6 Cyber Security for microgrids and DERs

7 NREL microgrid design process and campus overview

8 Example DOD Microgrids (If there’s time)

Resilience Framework for Electric Energy Delivery Systems (EEDS)

Idaho National Laboratories "Resilience Framework Electric Energy Delivery Systems"



Megan Culler and Stephen Bukowski - INL

https://resilience.inl.gov/wp-content/uploads/2021/07/21-50152_RF_EEDS_R4.pdf

Evaluating a Resilience Investment Requires Quantifying, Valuing, and Monetizing Its Impact on System Resilience

Quantifying Resilience

A resilience metric measures how resilient an energy system is. Performance-based metrics quantify the consequences that could be avoided as a result of a resilience investment:

- Customer outage time (hours)
- Load not served (kilowatt-hours)
- Number or percentage of customers experiencing an outage (# or %)
- Number of critical services (e.g., hospitals or fire stations) without power (#)
- Time to recovery (hours)
- Cost of recovery ($)

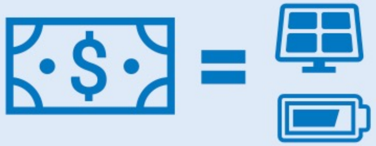
Valuing Resilience

$$$

Determining the value of a resilience investment (in dollars) is an essential component of cost-benefit analysis. An accurate resilience value involves determining the avoided costs of an outage, including the direct and indirect costs incurred by the service provider, customers, and society:

- Loss of utility revenue ($)
- Cost of grid damages ($)
- Cost of recovery ($)
- Avoided outage cost ($)
- Loss of assets and perishables ($)
- Business interruption costs ($)

Monetizing Resilience



Resilience monetization determines what portion of the resilience value can be realized in cash flow to finance project implementation. Beyond the improved resilience itself, such an evaluation should consider all available revenue streams associated with the investment:

- Reduced insurance rates
- Reduced mortgage rates
- Government incentives
- Grid services value
- Resilience payment from site host

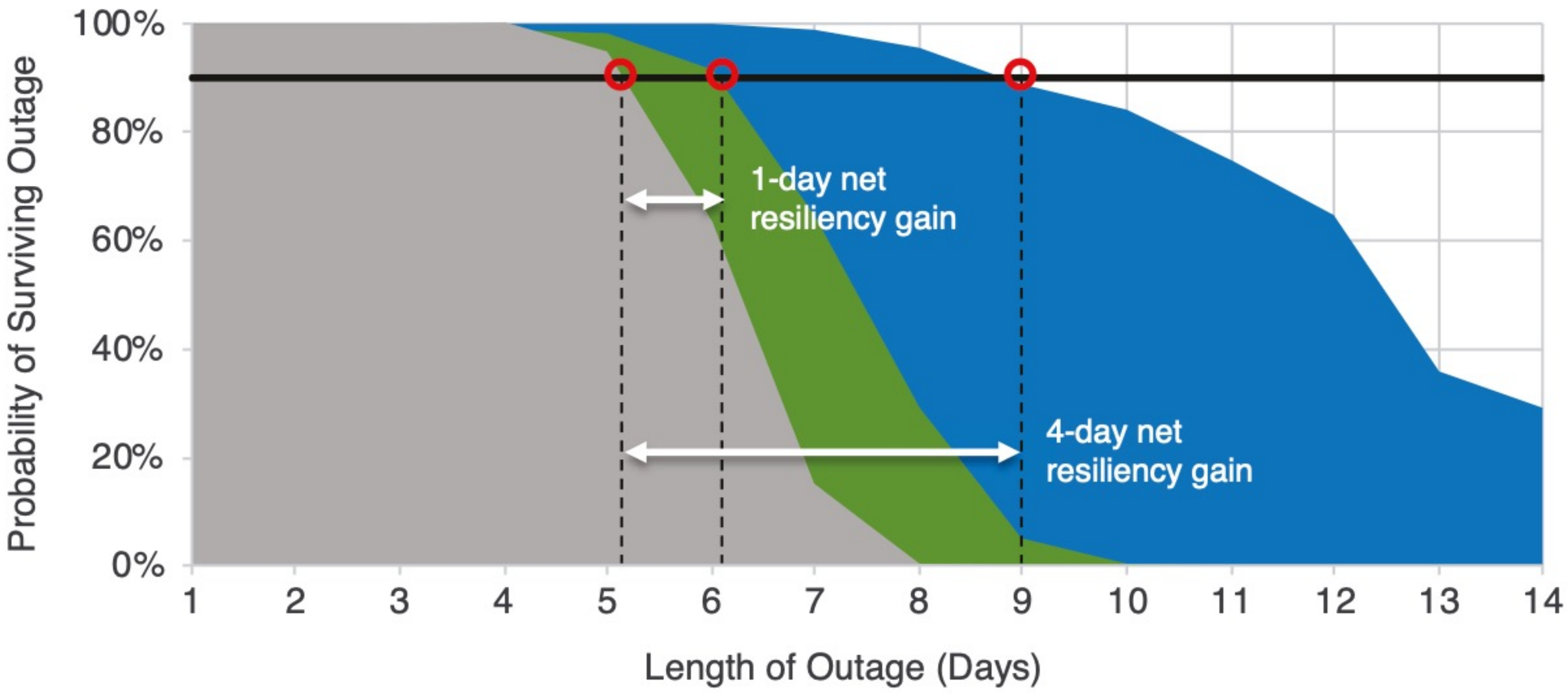
Kate Anderson and Eliza Hotchkiss - https://www.nrel.gov/docs/fy19osti/74673.pdf

Survivability Metric to Quantify Resilience

This curve can be generated two ways;

- Through partnerships with NREL where NREL researchers create a custom model for your load/power system, or
- Through REopt Lite – publicly available
    - https://reopt.nrel.gov/tool

	Generator	Solar PV	Storage	Life Cycle Cost	Outage
1. Base case	2.5 MW	-	-	$20 million	5 days
2. Lowest cost	2.5 MW	625 kW	175 kWh	$19.5 million	6 days
3. Proposed system	2.5 MW	2 MW	500 kWh	$20 million	9 days



K. Anderson et al., "Increasing Resiliency Through Renewable Energy Microgrids". SCTE Journal of Energy Management Vol.2 (2) August 2017 pp.22-38. https://www.nrel.gov/docs/fy17osti/69034.pdf

1 Resilience Definitions

2 Resilience Frameworks and Resilience Valuation

3 **Approaches to Resilience**

4 Standby Generation, Microgrids, and SmartGrids

5 Resilience Infrastructure O&M Considerations

6 Cyber Security for microgrids and DERs

7 NREL microgrid design process and campus overview

8 Example DOD Microgrids (If there’s time)

Achieving Resilience for Military Installations – An example for discussion purposes

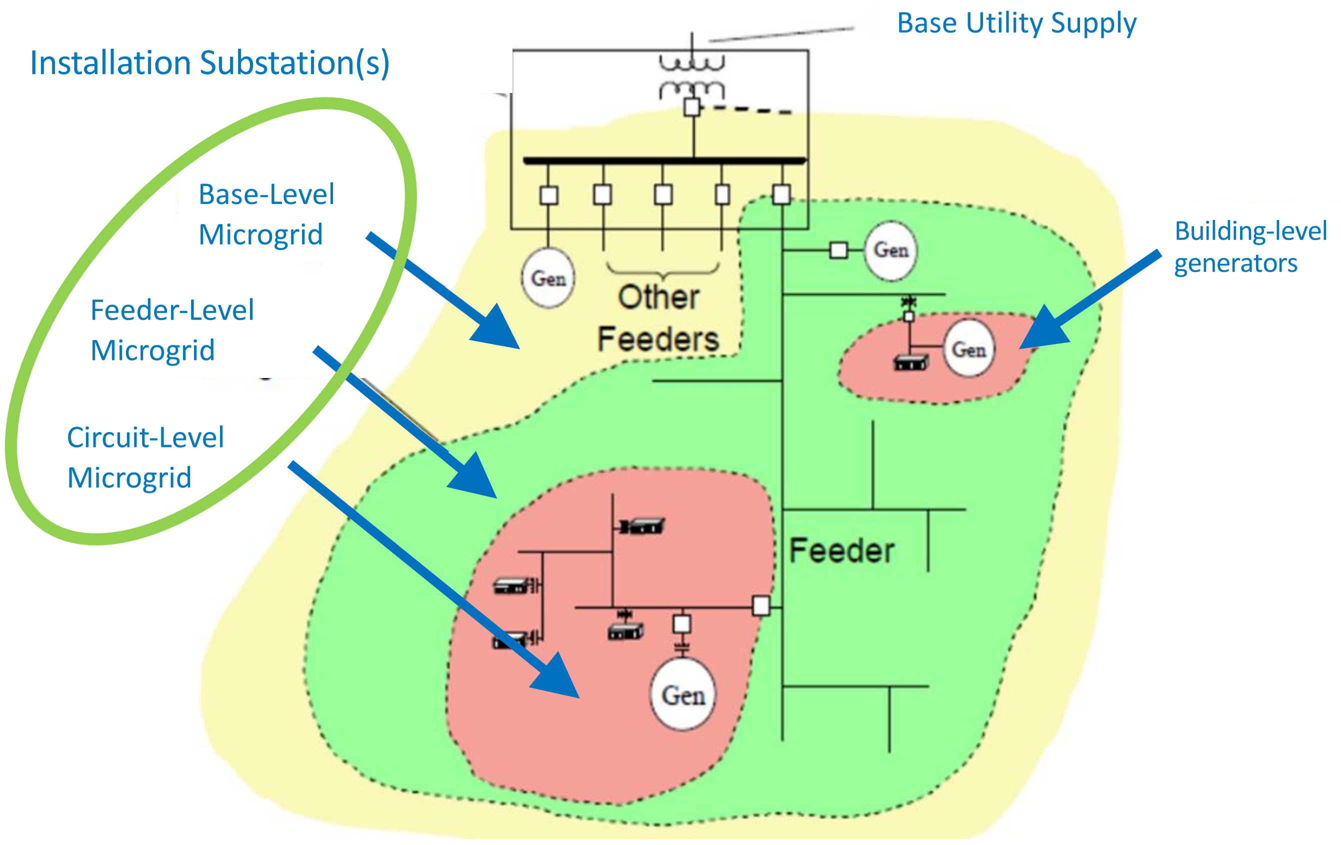
Example Configurations	Example risks during an outage	Lifecycle cost	Revenue/payback during normal operation?
1. Single substation/feeder connecting to an electric utility	Utility Outage=Base Outage, Others?	$	None
2. Additional substation/feeder(s) connecting to a utility	Utility Outage=Base Outage, Others?	$$	N/A
3. Building-tied standby generators (Commonly Diesel or Natural Gas)	Fuel Supply, Reliability of Generators, Maintenance	$$$	N/A
4. Base or feeder-level standby power plant (Commonly Diesel or Natural Gas)	Fuel Supply, Reliability of Generators, Maintenance	$$$$	N/A
5. Base or feeder-level microgrid with a central power plant (Commonly Diesel or Natural Gas)	Fuel Supply, Reliability of Generators, Maintenance	$$$$$	Some
6. Base or feeder-level **Smart microgrid** with central and **distributed generation** (Diesel or NG with solar, wind, BESS, etc)	Maintenance, Reliability of Generators, Cyber Security, Fuel Supply	$$$$$$	Yes

1. Resilience Definitions
2. Resilience Frameworks and Resilience Valuation
3. Approaches to Resilience
4. **Standby Generation, Microgrids, and SmartGrids**
5. Resilience Infrastructure O&M Considerations
6. Cyber Security for microgrids and DERs
7. NREL microgrid design process and campus overview
8. Example DOD Microgrids (If there's time)

What is a Microgrid?

Microgrid – DOE Definition

- A group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid.
- A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island mode.



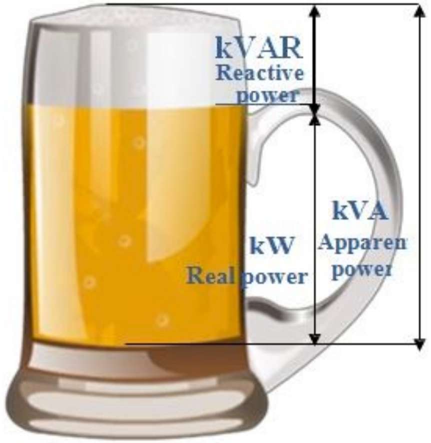
https://www.epri.com/#/pages/product/000000003002008205/?lang=en-US

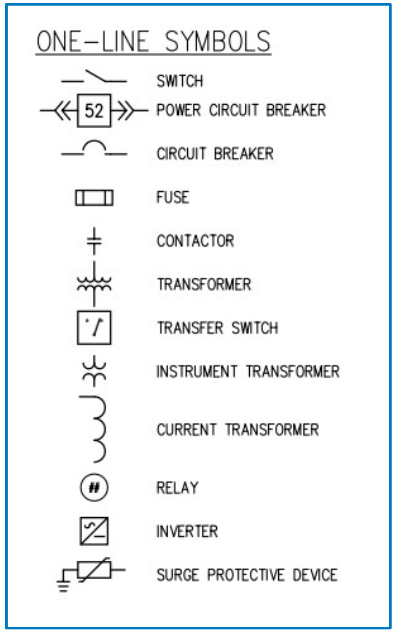
Components of Microgrids

Components

- Generation
- Energy storage
- Loads
- Transmission and Distribution Lines
- Switching and Protection Devices (manual and/or motor actuated)
  - Circuit Breaker
  - Disconnect Switch
  - Automatic Transfer Switch (ATS)
  - Reclosers
  - Fuses
- Power/voltage Correction
  - Voltage Regulator
  - Capacitor

Opening HV Air-break disconnect under load
(Not supposed to happen, but still cool!)

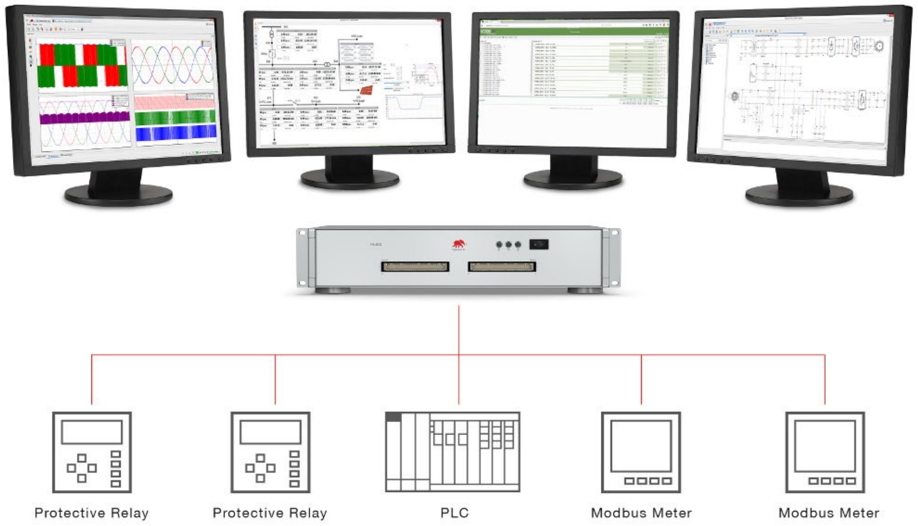




What is SmartGrid?

SmartGrid - DOE Definition

- Interconnected generation and loads enabled with remote **monitoring and controls** capabilities
  - Enabled through fiber, relays, central control system
  - Allows for central monitoring and controls
  - Workforce management to deploy personnel for O&M
  - Some functions can be automated based on set-points and desired operating conditions

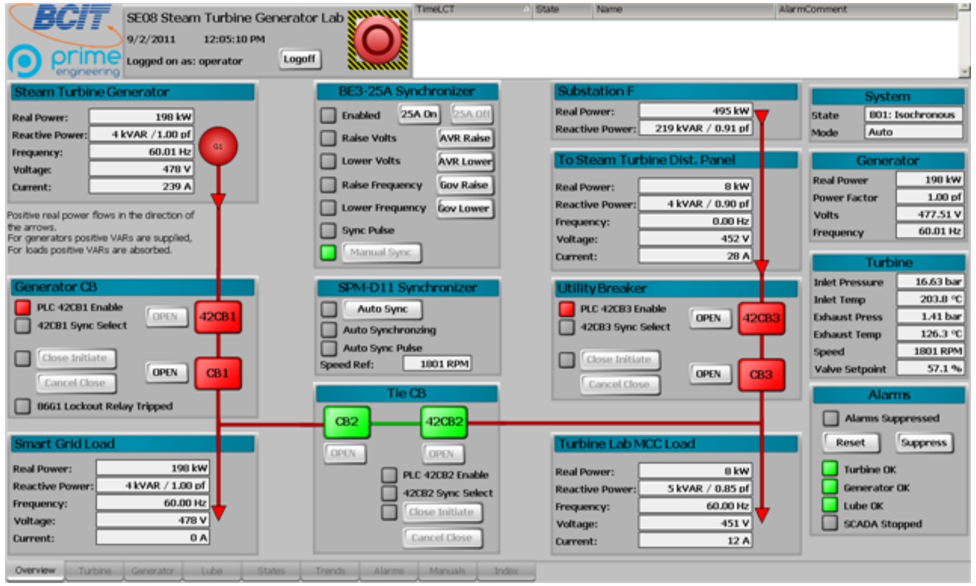


Components that Enable SmartGrid

- **Hardware**
  - Current Transformer (CT) and Potential Transformer (PT)
    - Transform high current/voltage to low current/voltage to become easier and cheaper to measure
  - Relays
    - Terminal point to convert data signal into action (ex open breaker, or ramp generator)
- **Communication**
  - Fiber Optic/Cat 6/radio or line signals
    - Carrier for signals between terminals
- **Software**
- SCADA/Hardware Machine Interface (HMI)
- Energy Management System
- Battery Management System
- Microgrid Controller
- Programmable Logic Controllers

Old Analog Relays

New Digital Relays



Controls of Microgrids and Smartgrids

Examples of levels…there are a limitless number of configurations

Basic

Grid-level generators that can island groups of loads from grid

- Connected generators can parallel
- Manual operation of all switching and generation

Intermediate

Grid-level generators that can remotely island loads from grid

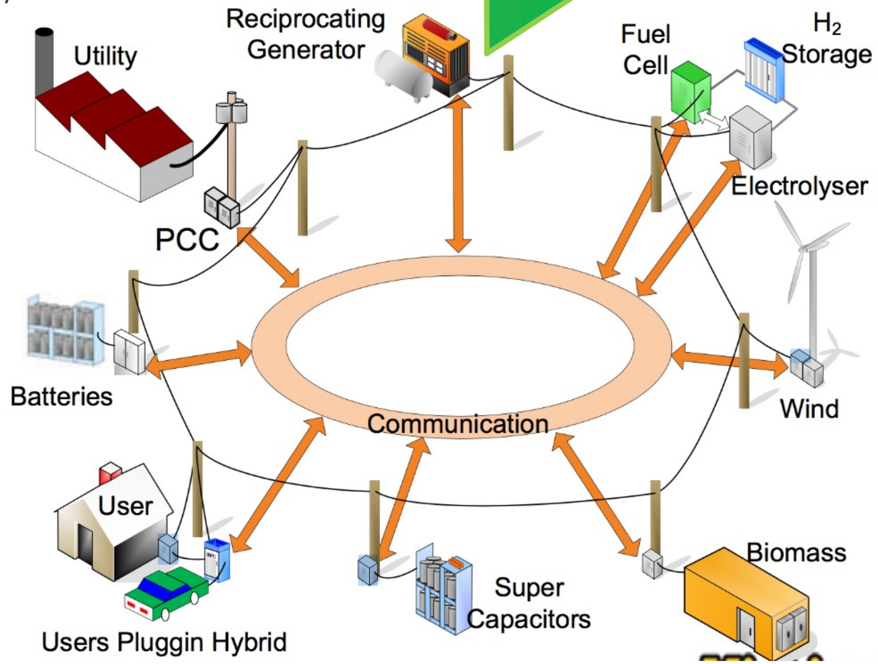
- System is half-automated, requires manual load shedding or isolation
- Generators can be remotely controlled once loads are shed

Advanced

Full Smart Microgrid capability

- Entire installation can be islanded
- Central control of load shedding
- Central control of generator output

- **"Smart Microgrid"** – Interconnected generation and loads capable of being operated and monitored remotely as an island from the public utility system
  - Smart Micrgrids consist of two major layers
    - **Microgrid layer** – electrical distribution
    - **SmartGrid layer** – controls and monitoring
- Smart microgrids can enable participation in markets for;
  - Frequency Regulation
  - Demand Response
  - Peak Shaving
  - Price Arbitrage/Load Shifting
  - Conservation Voltage Reduction (CVR)
  - Volt/VAR Support
  - Etc..



Conventional On-site Generation Sources on Military Installations

1. **Common DOD Standby Generators**
   - Engine Driven Generators (EDGs)
     - 5 kW to 5 MW
2. **Common DOD Standby Central Power Plants**
   - Diesel or NG EDGs or Combustion Turbines (CTs)
     - Multi-MW scale, typically

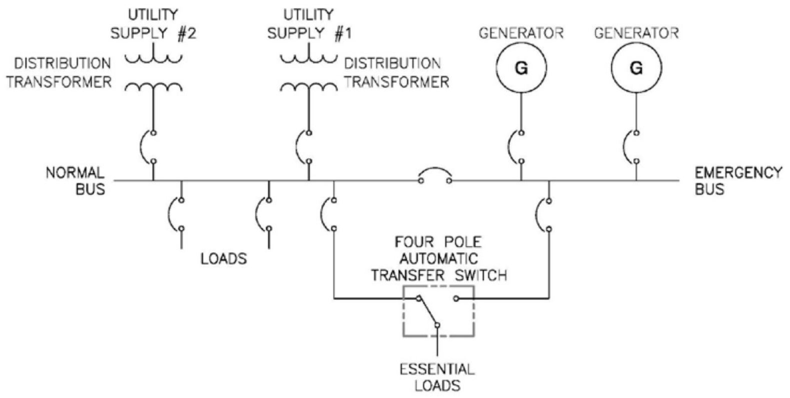
Benefits

- Standardized
- Simple
- Many others

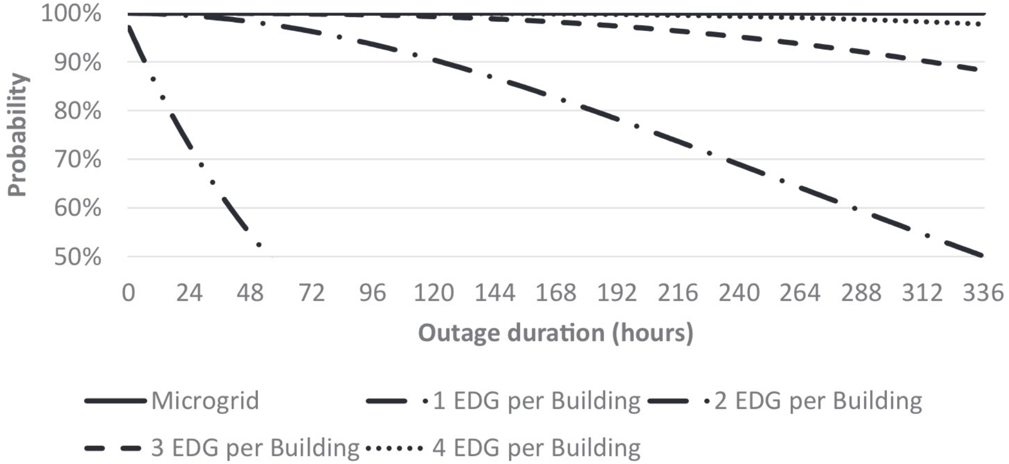
Concerns

- Fuel Supply (known risk)
- Maintenance (Cost and potentially a risk)
- Reliability
- Carbon Emissions (FY22 draft NDAA language)

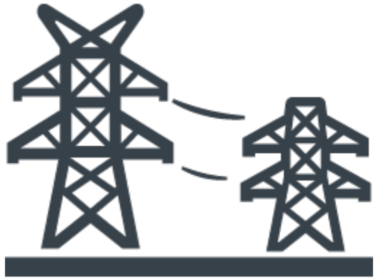
Figure B-8 Parallel Generators with Alternate Utility Supply



Source: Unified Facility Criteria 3_540_01
“Engine-Driven Generator Systems for Prime and Standby Power Applications”



Probability of meeting 25% of highest priority critical load for a large campus as a function of the number of stand-alone EDGs per building as compared to a microgrid.
Source: http://www.sciencedirect.com/science/article/pii/S0306261921000052



Vs

- **Grid-Tied Mode:**
  - Frequency is set by the grid
  - Microgrid sources can operate independently
  - Real and reactive power regulated at point of coupling
  - Voltage impacted locally by sources
  - Available fault current is high
  - Little impact from variable renewables and loads

- **Island Mode:**
  - Frequency set by grid-forming source
  - Sources will share load or output constant power
  - Sources will share reactive power
  - Voltage impacted locally by sources
  - Available fault current is low
  - Large impact from variable renewables and loads

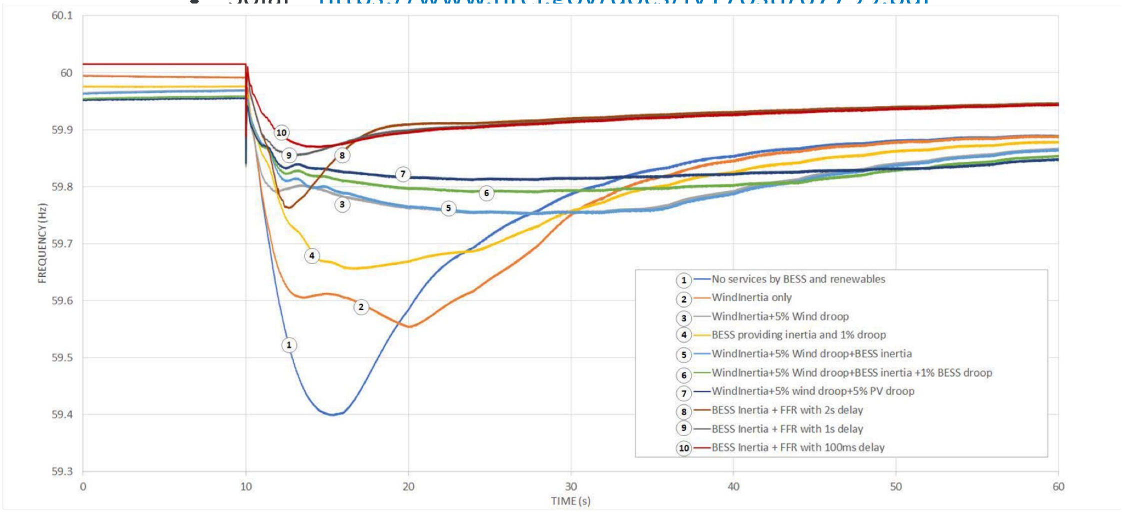
Variable Generation in a Microgrid

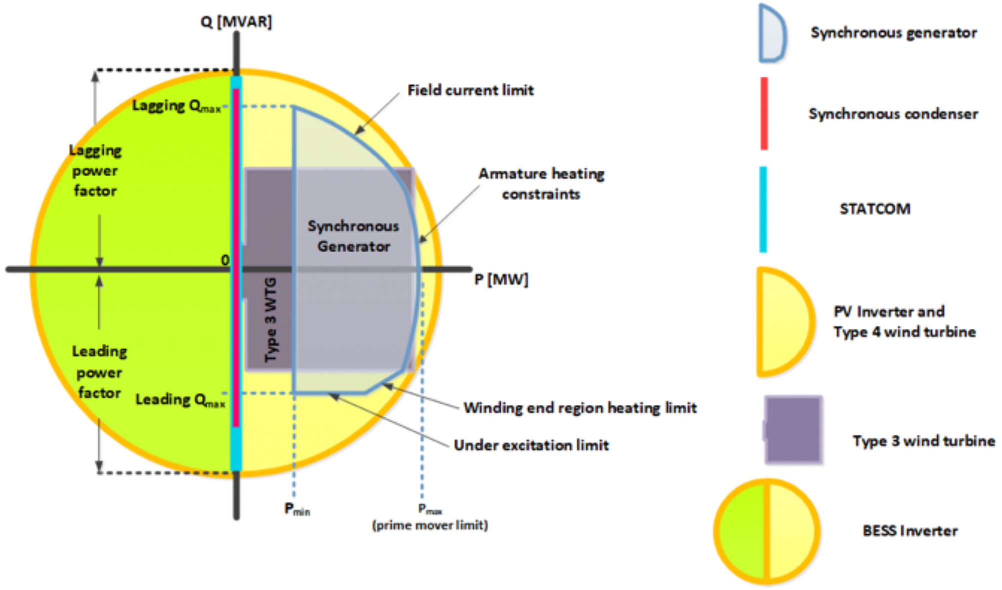
Microgrid Planning: Ensure that adequate capacity exists to serve peak load and blackstart the microgrid

- ❖ Peak load and average load are a large factor of generation capacity sizing, avoid overloading and wet-stacking
- ❖ Generation capacity must be capable of supporting in-rush currents during blackstart
  - ❖ In-rush currents are largely driven by power transformers and large motor loads.
- ❖ Capacity and Energy resources
  - – Variable energy resources should be viewed as an energy resource (kWh)
  - – 10 MW of solar PV and 10 MW of diesel cannot serve 20 MW of load, this can serve 10 MW of load with PV offsetting fuel use

Microgrid Operation: Generation will be dispatched based on system needs

- ❖ As load varies, generation will be adjusted to maintain a balanced and stable system
- ❖ Variable generation should be maximized to reduce fuel consumption when available, but may need to be curtailed to ensure adequate power quality and to avoid over-generation
- ❖ Renewables can provide grid services, many of these are resource dependent
  - ❖ Wind - https://www.nrel.gov/docs/fy19osti/72578.pdf
  - ❖ Solar - https://www.nrel.gov/docs/fy17osti/67799.pdf



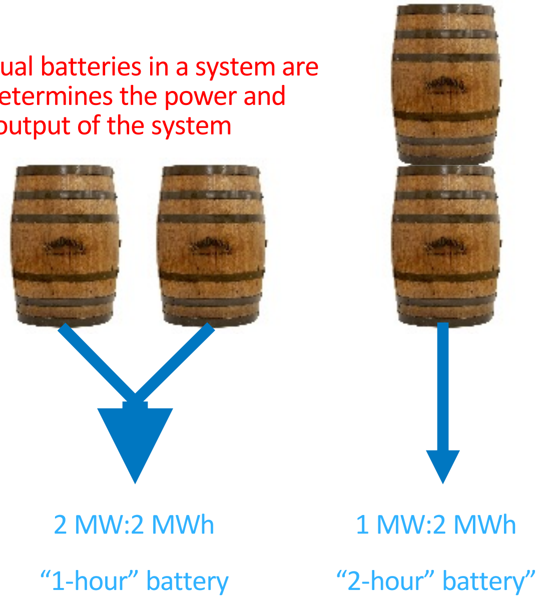


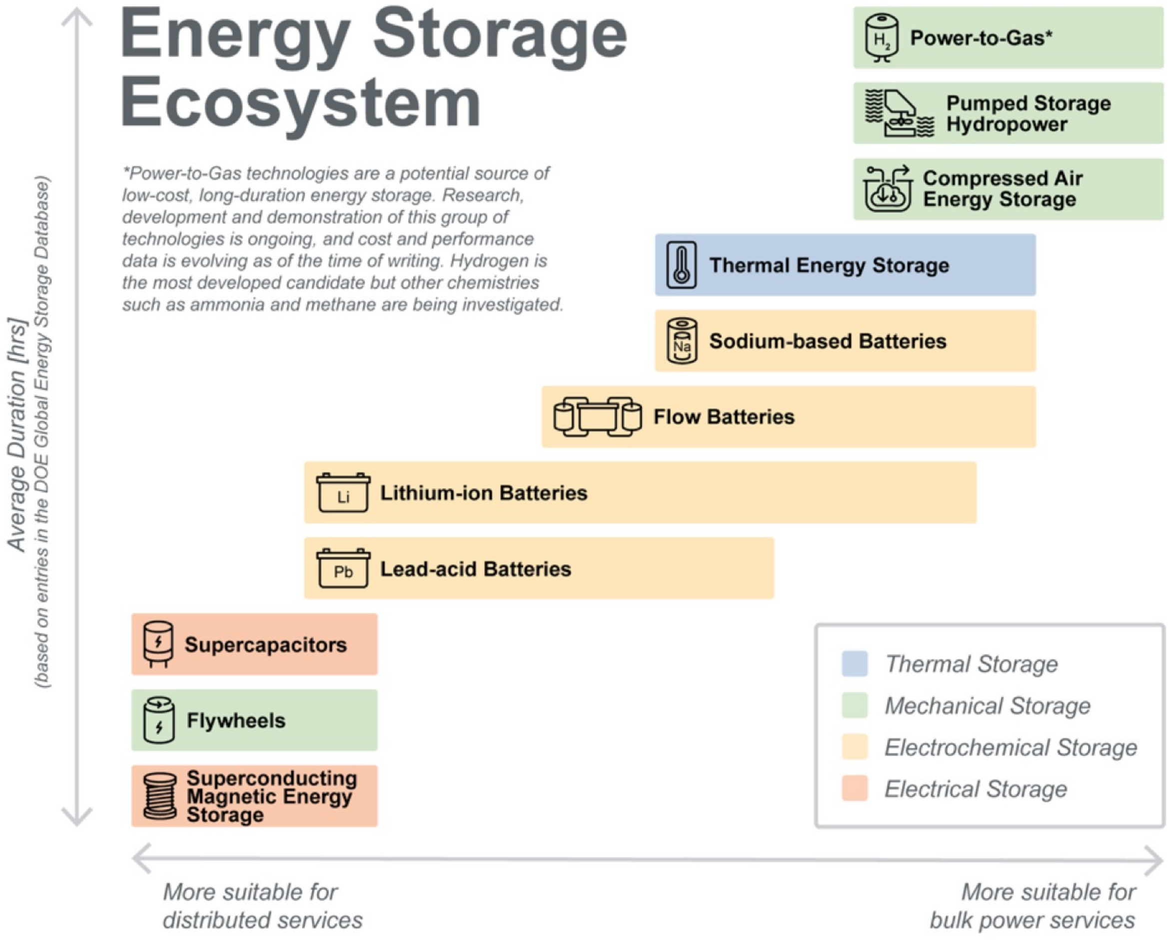
Source: NREL – Gevorgian, 2018

Battery Energy Storage System (BESS)

- Capacity of a BESS = MW
  - Similar to peak output of a diesel – the most power that can be injected
  - Output can be controlled through inverters up to specified capacity
- Energy of a BESS = MWh
  - Similar to the fuel storage for a diesel generator
- Simplified run-time of a BESS
  - MWh / MW_{load} = # of hours
  - 5 MWh BESS injecting 2 MW can run for 2.5 hours
  - 5 MWh BESS injecting 0.5 MW can run for 10 hours
  - 20 MWh BESS injecting 10 MW can run for 2 hours
    - At $1M per MWh, this gives **2 hours** of backup for a 10 MW load for $20M

How the individual batteries in a system are configured determines the power and energy output of the system





Source: https://www.nrel.gov/docs/fy21osti/76097.pdf

1 Resilience Definitions

2 Resilience Frameworks and Resilience Valuation

3 Approaches to Resilience

4 Standby Generation, Microgrids, and SmartGrids

5 **Resilience Infrastructure O&M Considerations**

6 Cyber Security for microgrids and DERs

7 NREL microgrid design process and campus overview

8 Example DOD Microgrids (If there’s time)

Resilience Infrastructure O&M Considerations (For Discussion Purposes)

- **Diesel and Natural Gas Generation**
  - Preventative maintenance of standby and prime generators (UFC 3-540-07)
- **Renewable-specific O&M**
  - UFC guidance (UFC 3-440-01, UFGS 48 14 00, and UFGS 48 15 00)
- **Control Systems**
  - Cyber Security (UFC 4-010-06 and UFGS 25 05 11)
  - Network Maintenance (UFGS 25 10 10)
- **Energy Storage**
  - Preventative Maintenance (https://rules.dnv.com/docs/pdf/DNV/rp/2017-09/dnvgl-rp-0043.pdf – Section 4.8)
  - Recapitalization
- **Distribution Network Infrastructure**
  - Preventative Maintenance and Recapitalization (UFC 3-550-07)
- **Contracting Mechanisms?**
  - BOS contractor?
  - Local utility (UESC?)
  - Utilities Privatization?
  - Other Transaction Authority?
  - Energy Savings Performance Contracts?
  - Others?

1 Resilience Definitions

2 Resilience Frameworks and Resilience Valuation

3 Approaches to Resilience

4 Standby Generation, Microgrids, and SmartGrids

5 Resilience Infrastructure O&M Considerations

6 Cyber Security for microgrids and DERs

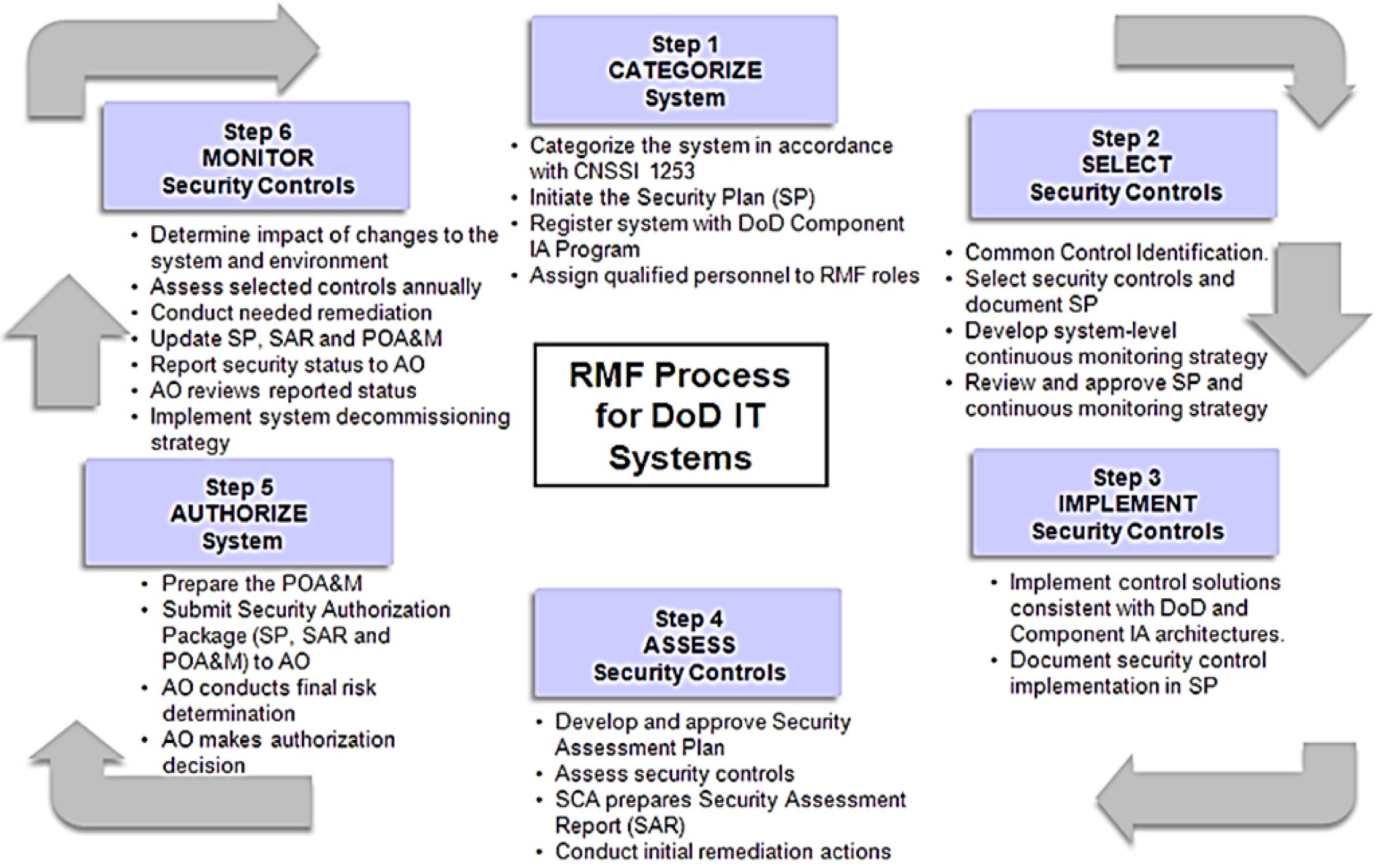
7 NREL microgrid design process and campus overview

8 Example DOD Microgrids (If there’s time)

DOD Cyber Security Risk Management Framework Process for ATO

To receive "Authority to Operate" (ATO) all Industrial Control Systems on DOD bases must go through the DOD RMF Process outlined in DODI 8510.01 – 2016

- SCADA
- Smartgrid networks
- Building Automation Systems
- power system control networks
- And many others



Cybersecurity of Facility-Related Control Systems

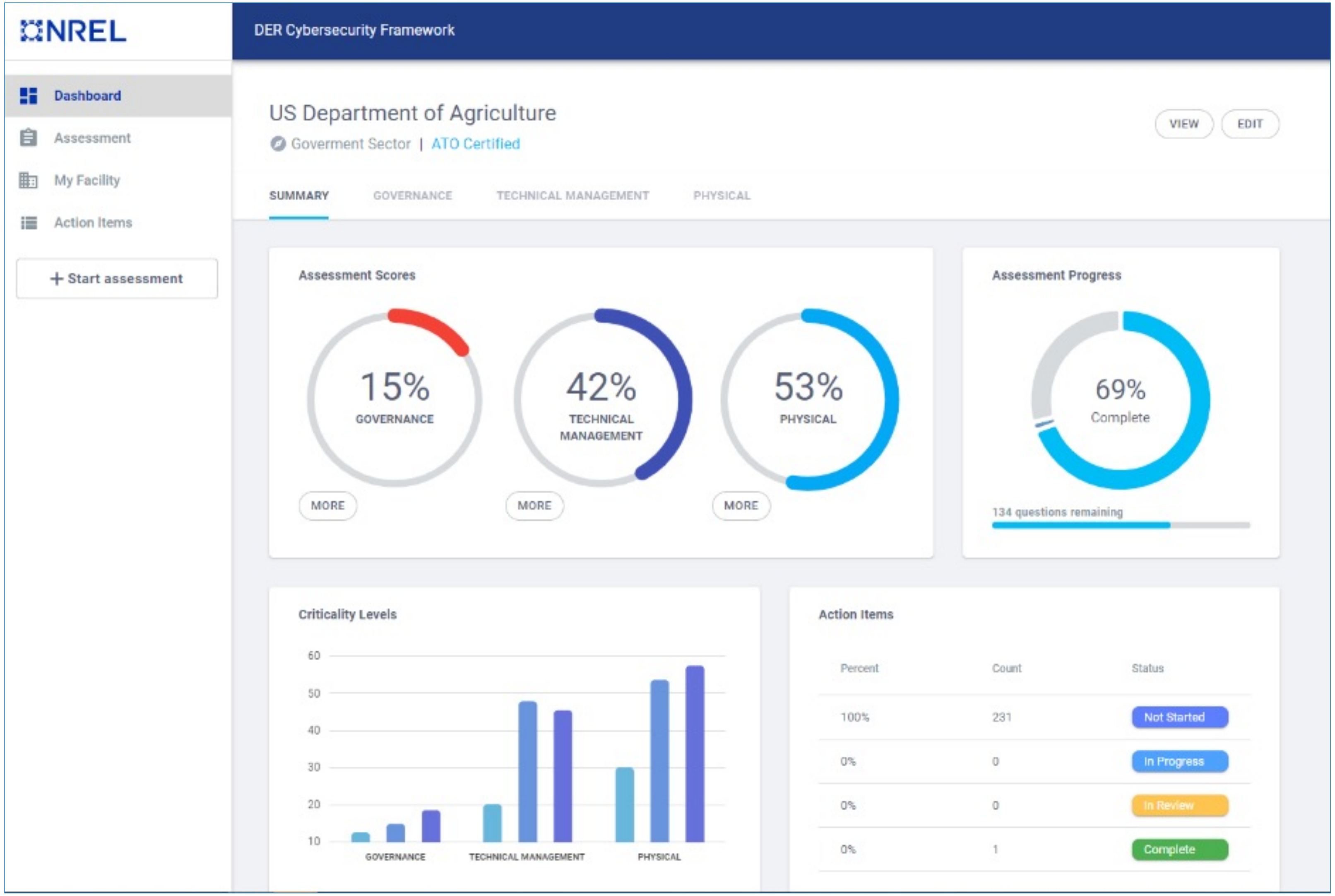
Figure C-3: Risk Management Framework Steps

https://www.wbdg.org/FFC/DOD/UFC/ufc_4_010_06_2016_c1.pdf

Distributed Energy Resources Cybersecurity Framework (DER-CF)

The DER-CF provides a holistic assessment for evaluating the cybersecurity posture of DER systems. Available as a written guide or interactive Web tool, the DER-CF expands upon existing cybersecurity frameworks for more modern energy systems.

The DER-CF informs policies and controls for **cyber governance, cyber-physical technical management, and physical security of distributed energy technologies** at federal sites across the country.



Learn more about the tool: www.dercf.nrel.gov

1 Resilience Definitions

2 Resilience Frameworks and Resilience Valuation

3 Approaches to Resilience

4 Standby Generation, Microgrids, and SmartGrids

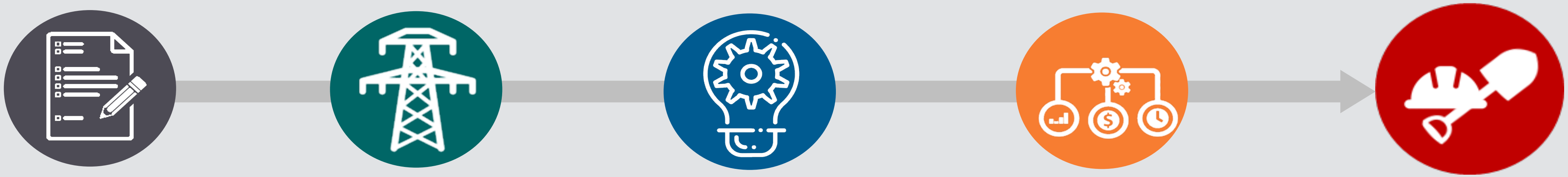
5 Resilience Infrastructure O&M Considerations

6 Cyber Security for microgrids and DERs

7 **NREL microgrid design process and campus overview**

8 Example DOD Microgrids (If there's time)

NREL Microgrid Design Process



Step One
Scoping & Planning

- Project Team
- Background Information
- Stakeholders
- Priority Missions & Loads
- Risks/Threats
- High Level Goals
- Performance requirements

Step Two
Data Collection

- Total Loads & Critical Loads
- Electrical Infrastructure
- Existing Generation & Future Potential
- Controls & Communications
- Energy Costs
- Historical Reliability

Step Three
Conceptual Design

- Boundaries & Architecture
- Generation Analysis & Selection
- Controls & Comms
- Design Constraints & Requirements
- Technical & Economic Modeling
- Implementation Options

Step Four
Project Development

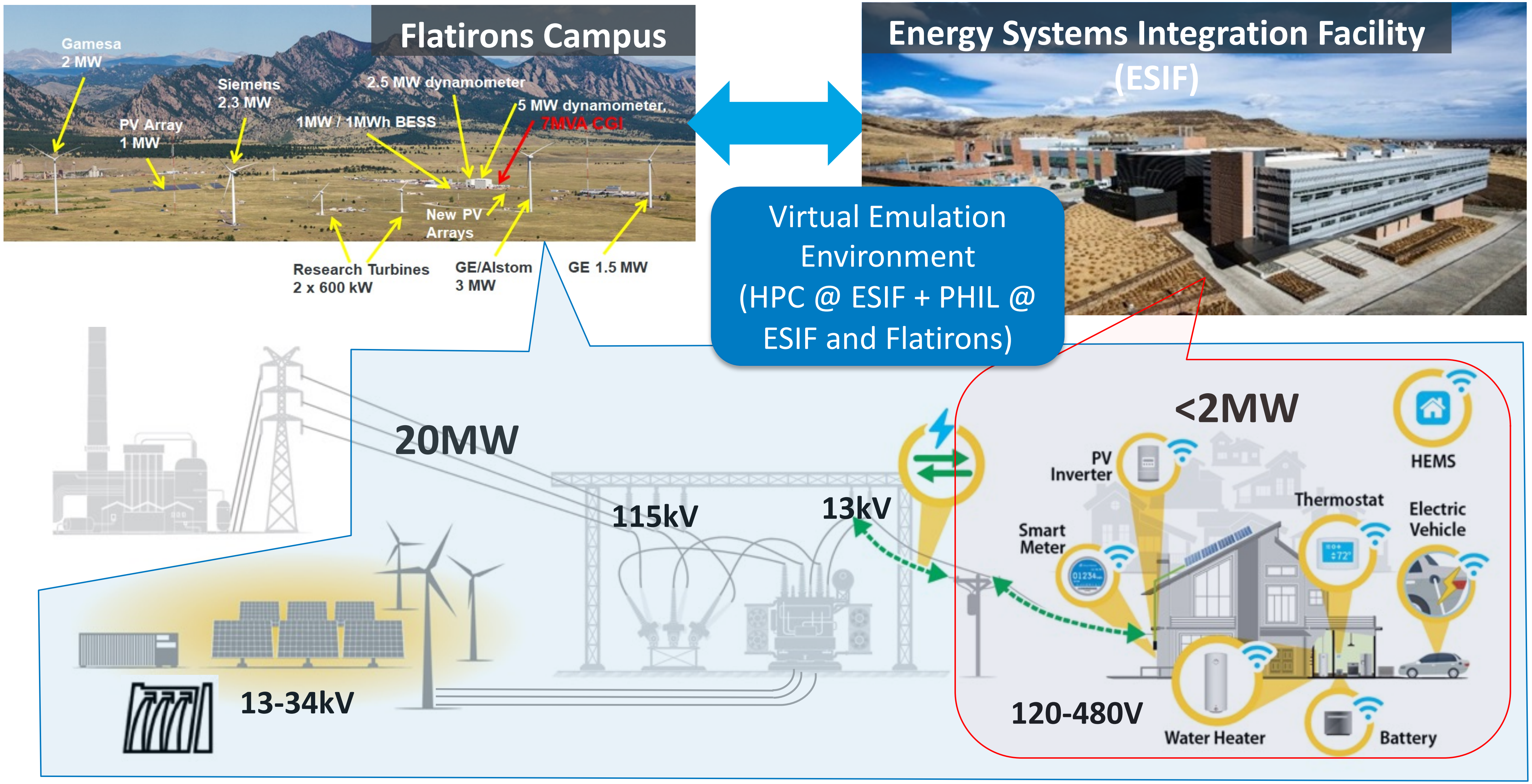
- Acquisition & Operating Strategies
- Funding or Financing
- Project Refinement
- Request for Proposal Development
- Solicitation
- Contractor Selection

Step Five
Implementation

- Post Award
- Engineering Design
- Construction & Functional Testing
- Commissioning & Performance Testing
- Operations & Maintenance

Microgrids for Energy Resilience: A Guide to Conceptual Design and Lessons from Defense Projects

NREL's Flatirons Campus and Energy System Integration Facility



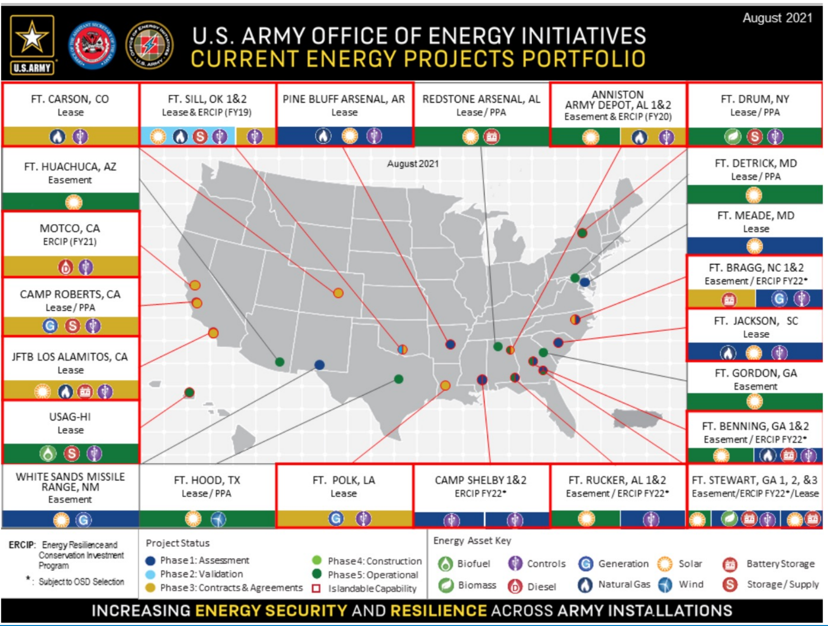
Bulk Generation, Storage, and MD/HD Mobility

Transmission/ Distribution & Storage

Distributed Generation, Storage, Loads, and LD Mobility

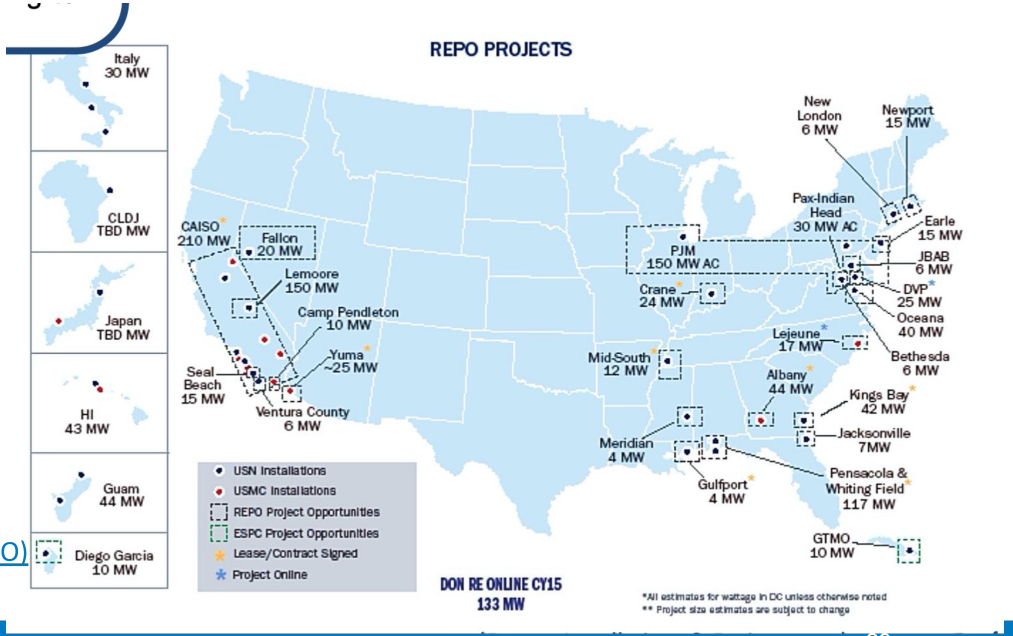
FY22 NDAA – Approved by House

- Section 2482
  - (A) The Secretary of Defense shall amend the Unified Facilities Criteria/DoD Building Code (UFC 1-200-01) to require that planning and design for military construction projects inside the United States include consideration of the feasibility and cost-effectiveness of installing an energy microgrid as part of the project, including intentional islanding capability of at least seven consecutive days, for the purpose of ……..
  - (B) - Contracts for Emergency Access to Existing On-installation Renewable Energy Sources.--In the case of a covered renewable energy generating source located on a military installation pursuant to a lease of non-excess defense property under section 2667 of title 10, United States Code, the Secretary of the military department concerned is encouraged to negotiate with the owner and operator of the renewable energy generating source to revise the lease contract to permit the military installation to access the renewable energy generating source during an emergency. The negotiations shall include consideration of the ease of modifying the renewable energy generating source to include an islanding capability, the necessity of additional infrastructure to tie the renewable energy generating source into the installation energy grid, and the cost of such modifications and infrastructure.



[Army Office of Energy Initiatives (OEI)]

[Navy Resilience Energy Program Office (REPO)]



Thank you!

www.nrel.gov

NREL

NATIONAL RENEWABLE ENERGY LABORATORY

1 Resilience Definitions

2 Resilience Frameworks and Resilience Valuation

3 Approaches to Resilience

4 Standby Generation, Microgrids, and SmartGrids

5 Resilience Infrastructure O&M Considerations

6 Cyber Security for microgrids and DERs

7 NREL microgrid design process and campus overview

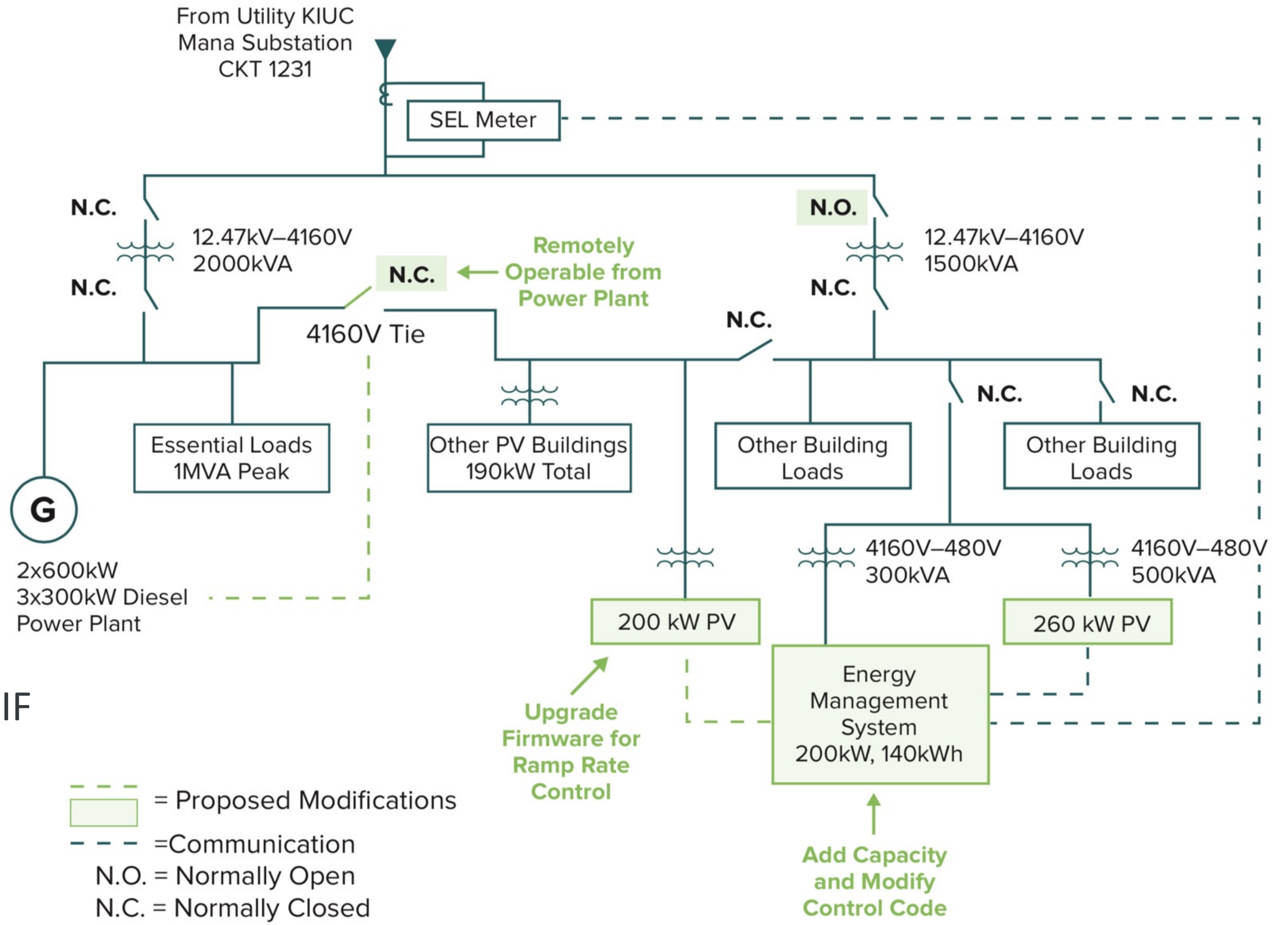
8 Example DOD Microgrids (If there's time)

Example PMRF ESTCP: Range Ops and Admin Area Microgrid

Microgrid Components:
- 600 kW Rooftop PV
- 2100 kW Central Diesel Power Plant
- 200 kW : 140 kWh BESS
- Energy Management System

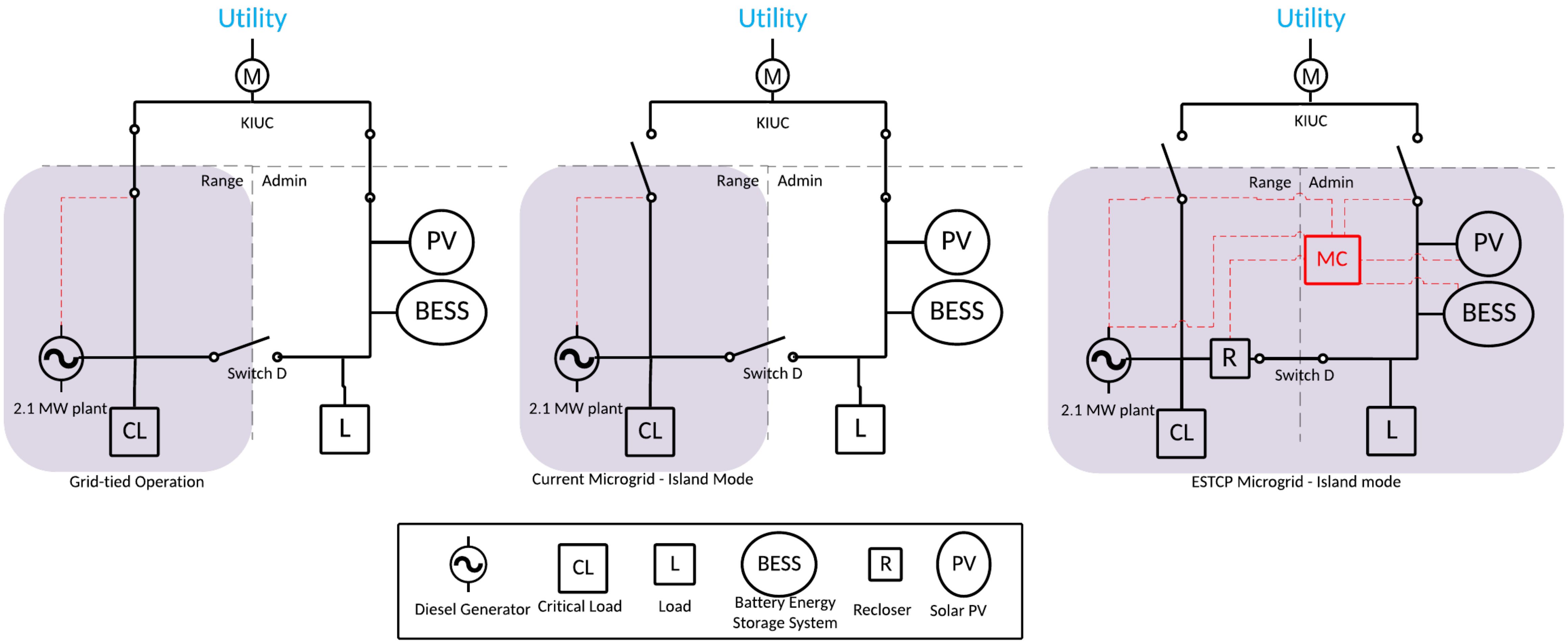
Objective
- Fully Enable Rooftop PV
- Peak Shaving with BESS
- Advanced inverter functionality
- Maintain or increase power quality
- Reactive power support (Volt/VAR)
- Navy RMF ATO process
  - Cyber security penetration testing at NREL ESIF

POCs
- Stephen Pereira - PMRF
- Charles Morris – KBR



Source: Navy PMRF, KBR Wyle, PowerSecure, and NREL

Example PMRF ESTCP: Existing grid-tied vs. New Islanded Operation



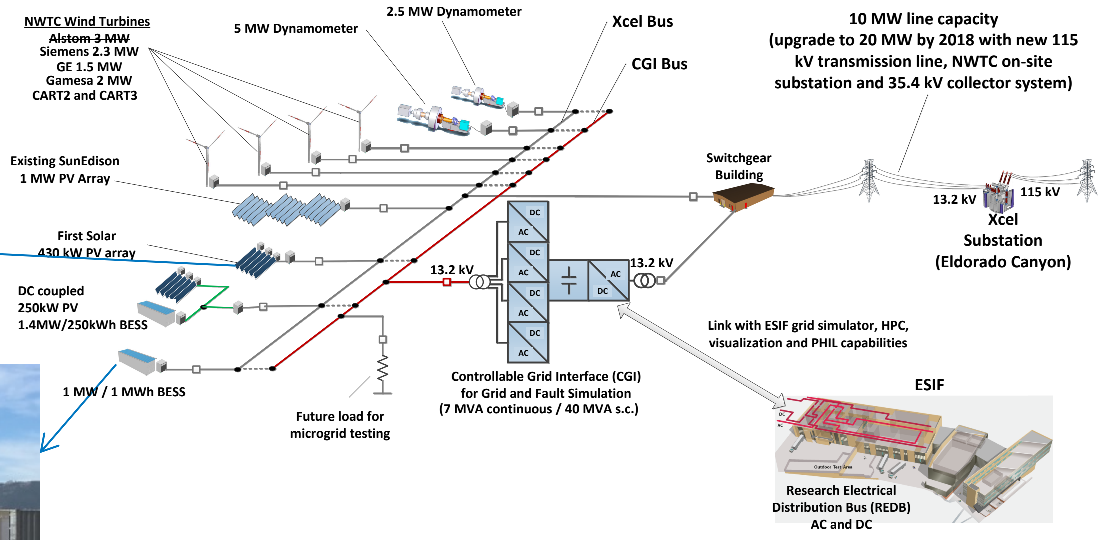
Example EUL Microgrid : Community Scale PV, Storage, and Microgrid for PMRF and Kauai Community

- NREL supported the Navy with the development of a 19.3 megawatts of PV with 30 MW : 70 MWh of energy storage
- The Utility, (KIUC) and AES partnered to develop the project
- PV and Storage will provide renewable power after sunset to meet island peak load
- Capable to supporting PMRF's mission-critical activities in the event of a short-term or extended grid outage
- NREL supporting hardware-in-the loop testing for microgrid controls at Flat Irons Campus
- During the CGI demonstration, AES stated that the PV and BESS system could run the installation "indefinitely".

Photo: AES Corporation

430 kW PV array
Scaled to 19.3 MW

1 MW/1 MWh battery
Scaled to 30 MW : 70 MWh



Example Microgrid: MCAS 29 Palms

Existing infrastructure:
- Connection to SCE through Rule 21
- COGEN 1 – 7.2 MW
- COGEN 2 – Two 4.2 MW
- ~9.2 MW PV

Add base-wide microgrid
- Increased resilience – Seamless transition at utility PCC
- Improved grid-tied operations – ability to shift load and manage system from two prime locations
- Fast load shedding – Quickly disconnect loads (<20 cycles) at some substations
- Load Management – Manage load at most/all substations using SCADAMates

Complications
- Large distribution system – complicated device management
- Communication network –existing and new communications infrastructure
- Fast load shedding – varying data types created system latencies
- Protection coordination – multiple protection settings required

MCAS POC
- David Velderman - USMC
- Clovis Vaughn - USMC

Photo Credit Cpl. Medina Ayala-Lo

Example Microgrid Joint Base Cape Cod Otis - ESTCP

Microgrid Components:

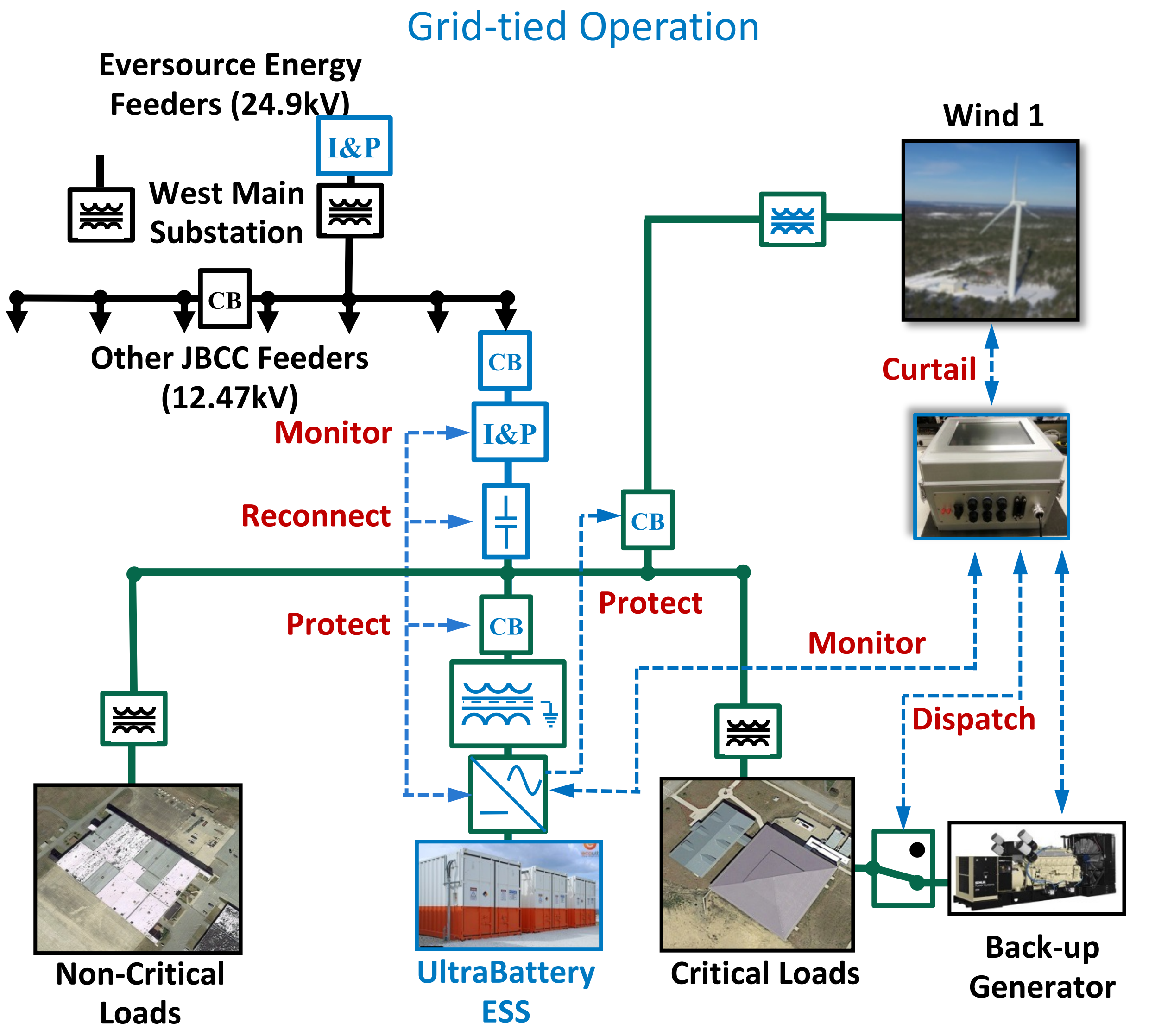
- 1.5 MW Standby Diesel Generator
  - Existing, reconfigured
- 1.5 MW : 2.2 MWh Lead-Acid UltraCapacitor Battery
  - New
- 1.5 MW GE Wind Turbine
  - Existing, reconfigured

Demonstration Objective

- Behind-the-Meter Battery participating in Frequency Regulation Market in ISO-NE
- Primarily Wind/BESS microgrid for 120 hours
- Reconfigure existing standby diesel
- Reduce reliance on diesel fuel
- Alternative purpose/options for standby diesel generators
- Maintain or improve power quality per IEEE 1547.4

POCs

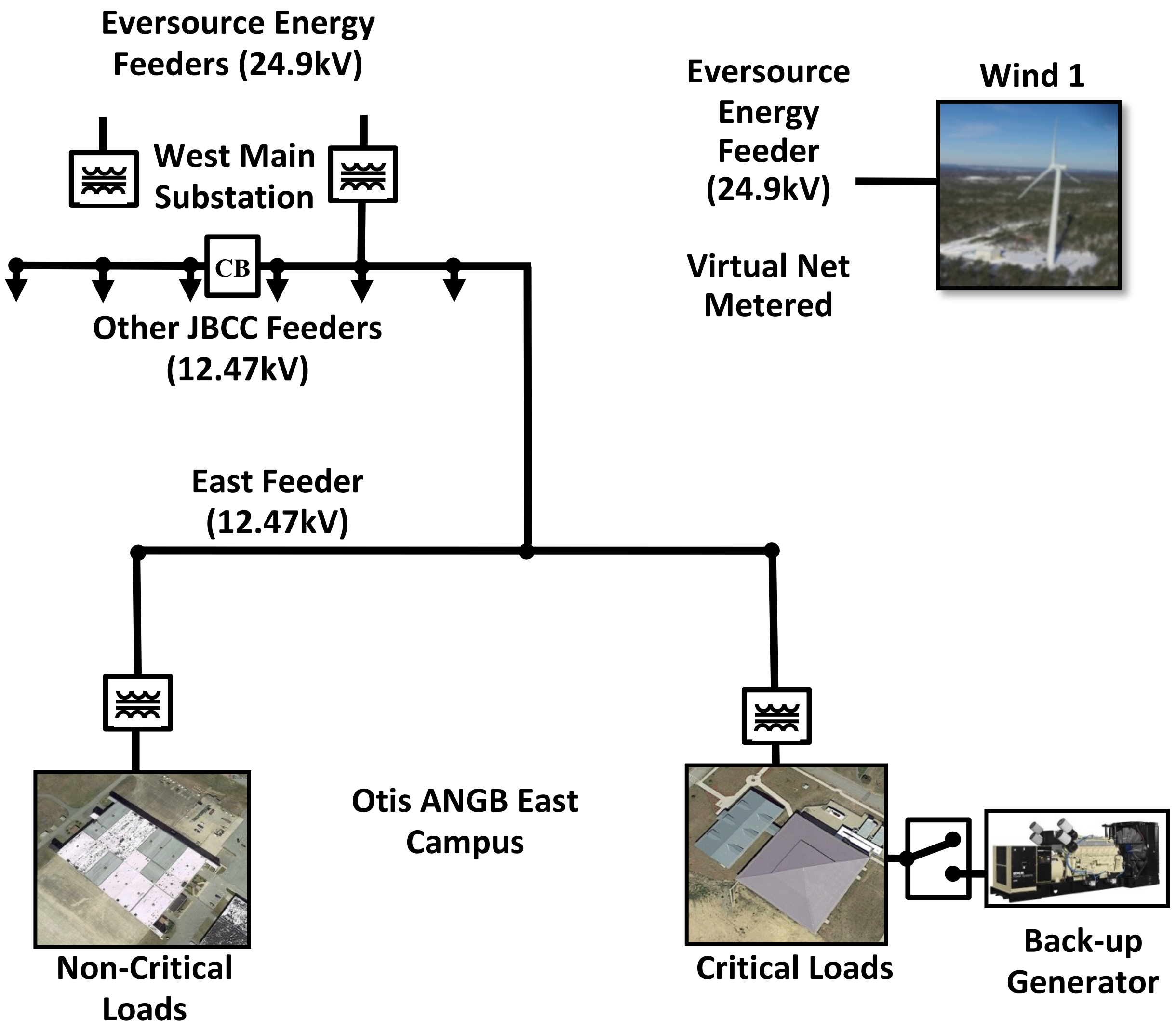
- Major Shawn Doyle – Air National Guard
- Dave Altman - Raytheon



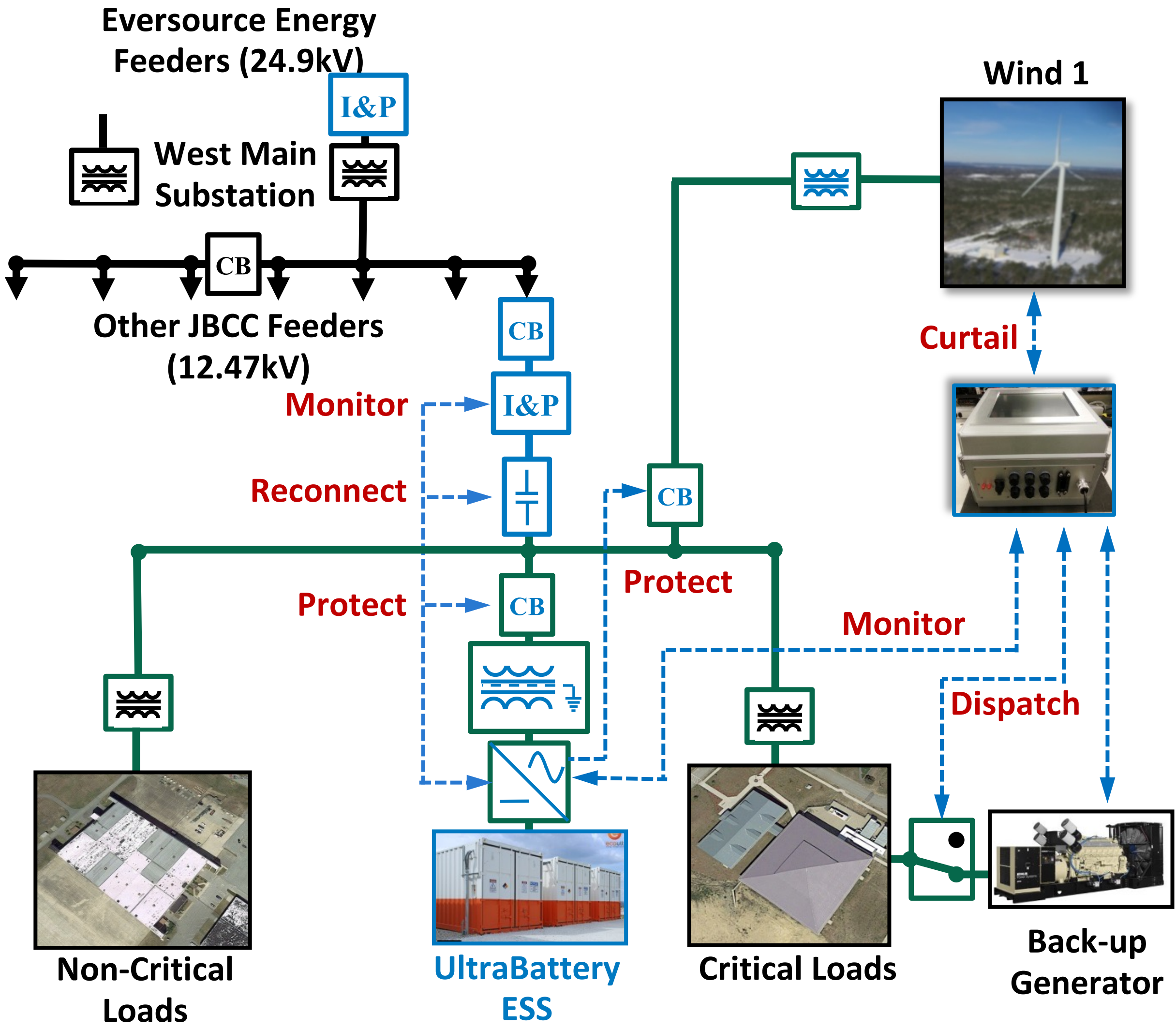
Source: Raytheon Integrated Defense Systems – Dave Altman

JBCC Otis Microgrid – Existing Configuration and Future Normal Operation

Existing Configuration (Pre-microgrid)



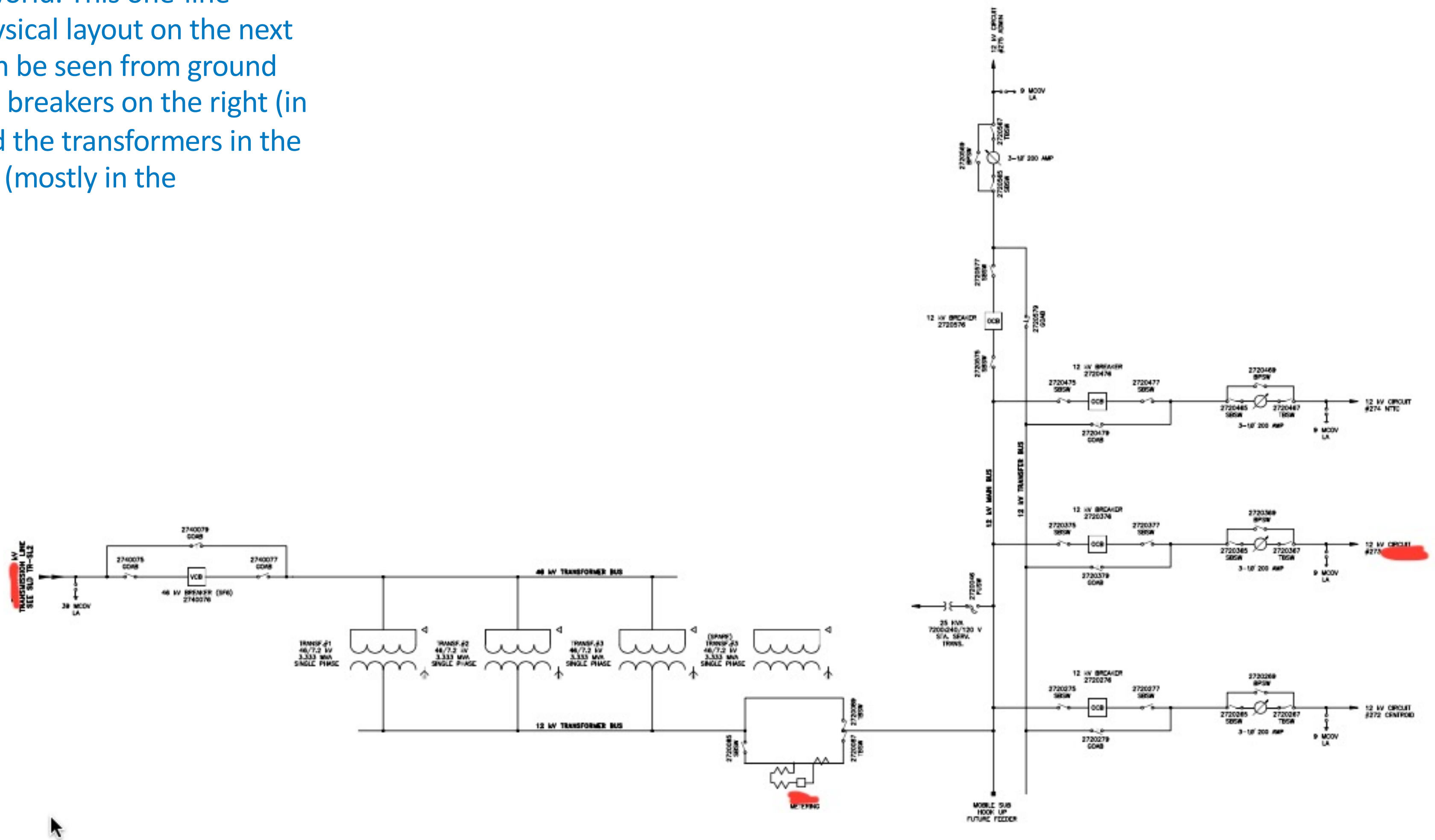
Future Configuration (Post microgrid)



Source: Raytheon Integrated Defense Systems – Dave Altman

Substation Example(page 1 of 3)

Takeaway: Electrical drawings correspond directly to the real world. This one-line correlates to the physical layout on the next slide, which then can be seen from ground level with the circuit breakers on the right (in the fore ground) and the transformers in the center of the screen (mostly in the background)



Substation Example(page 2 of 3)

Substation Example(page 3 of 3)