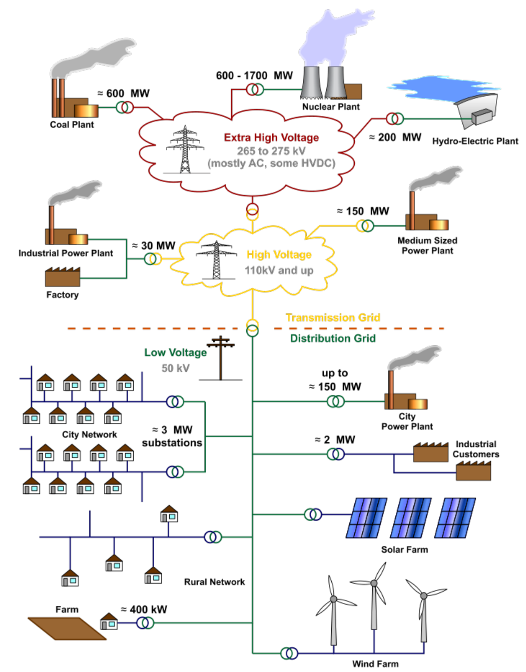
Microgrids

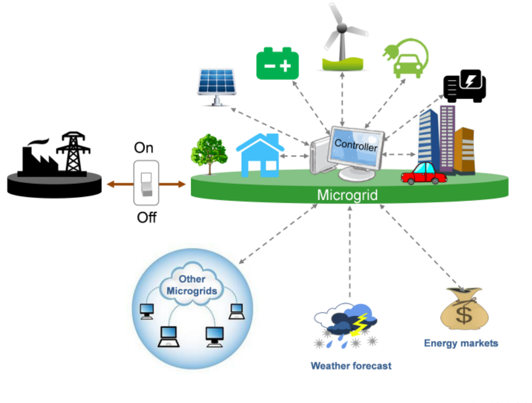
A distributed power network solution

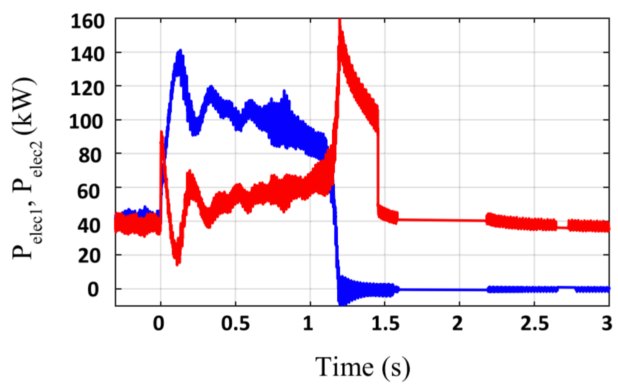
Tim Menke
Harvard Energy Journal Club
6 April 2018

Outline

- Recap: Traditional power grids & their problems
- What are microgrids?
- Advantages and challenges of microgrids
- Focus: Smart controller for orchestrating small, fluctuating sources
- Examples of microgrid projects







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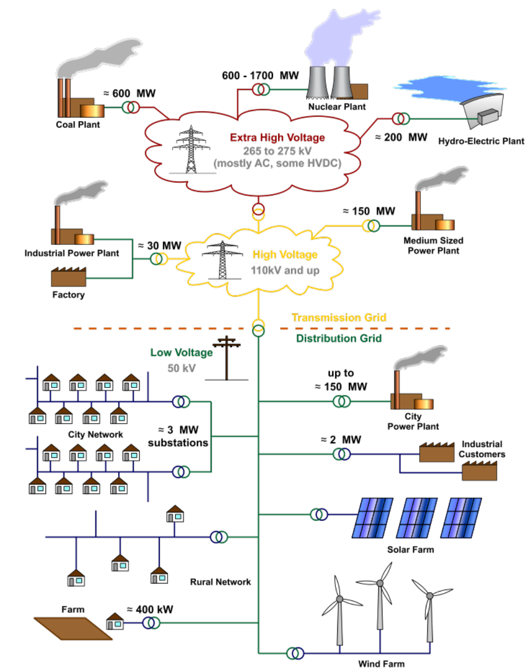
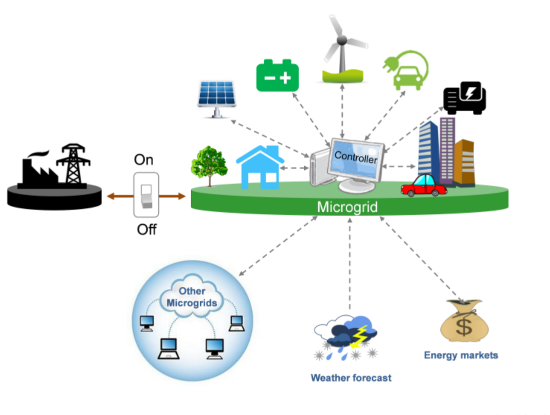
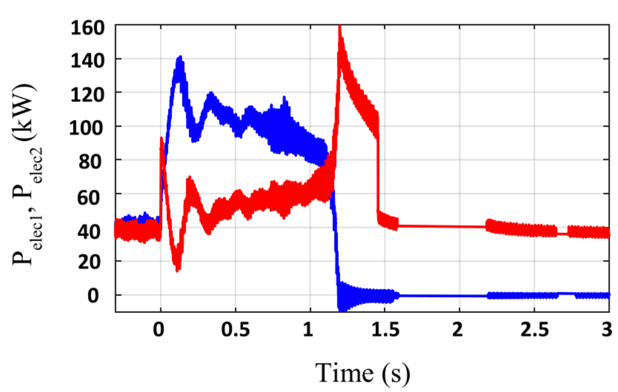
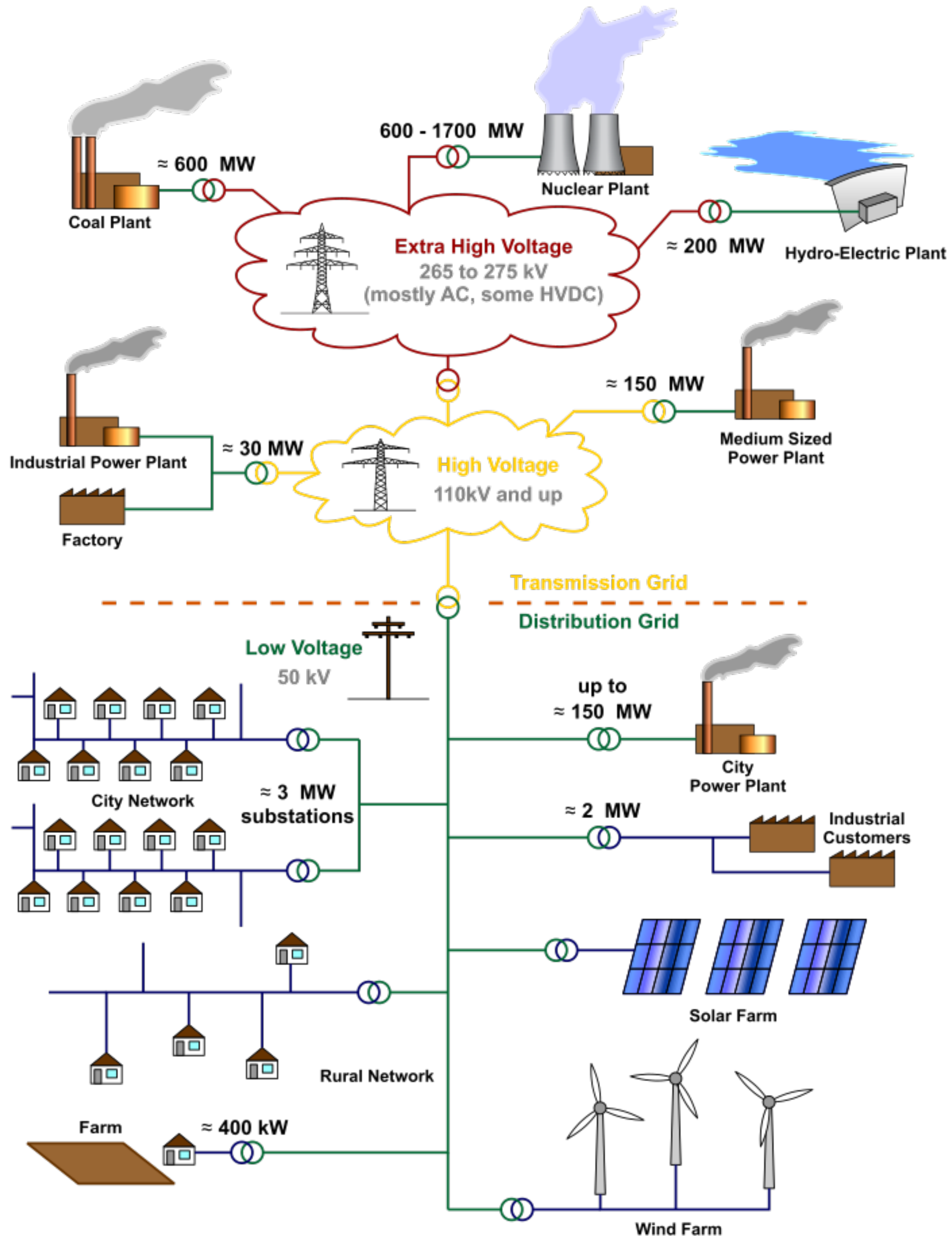






Recap: Traditional power grid



- Dominated by large-scale producers
- High voltage for transmission, low voltage for distribution
- Centralized operation by ISOs and RTOs
- Local sources are hard to monitor and control
  - Monitoring only indirect through frequency change

https://en.wikipedia.org/wiki/Electrical_grid

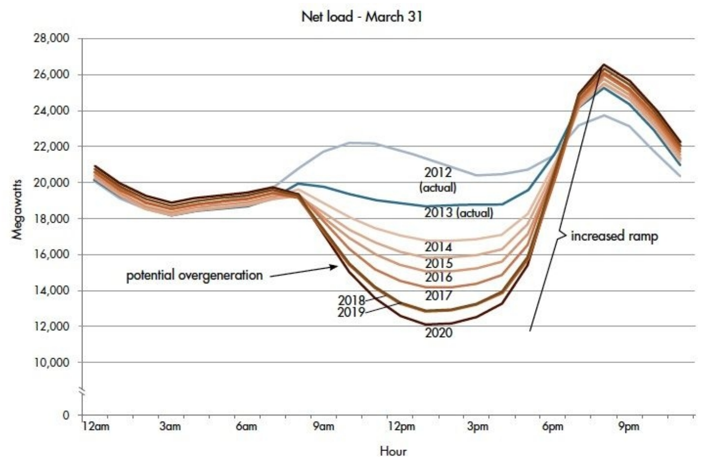
Problems of electrical grids worldwide

Developed world

- Difficult to integrate small, local sources into centralized, rigid grid
- In natural disasters, damage to parts of grid can lead to failure of whole
- Utility companies have large power over energy source composition and compensation for feeding back into grid

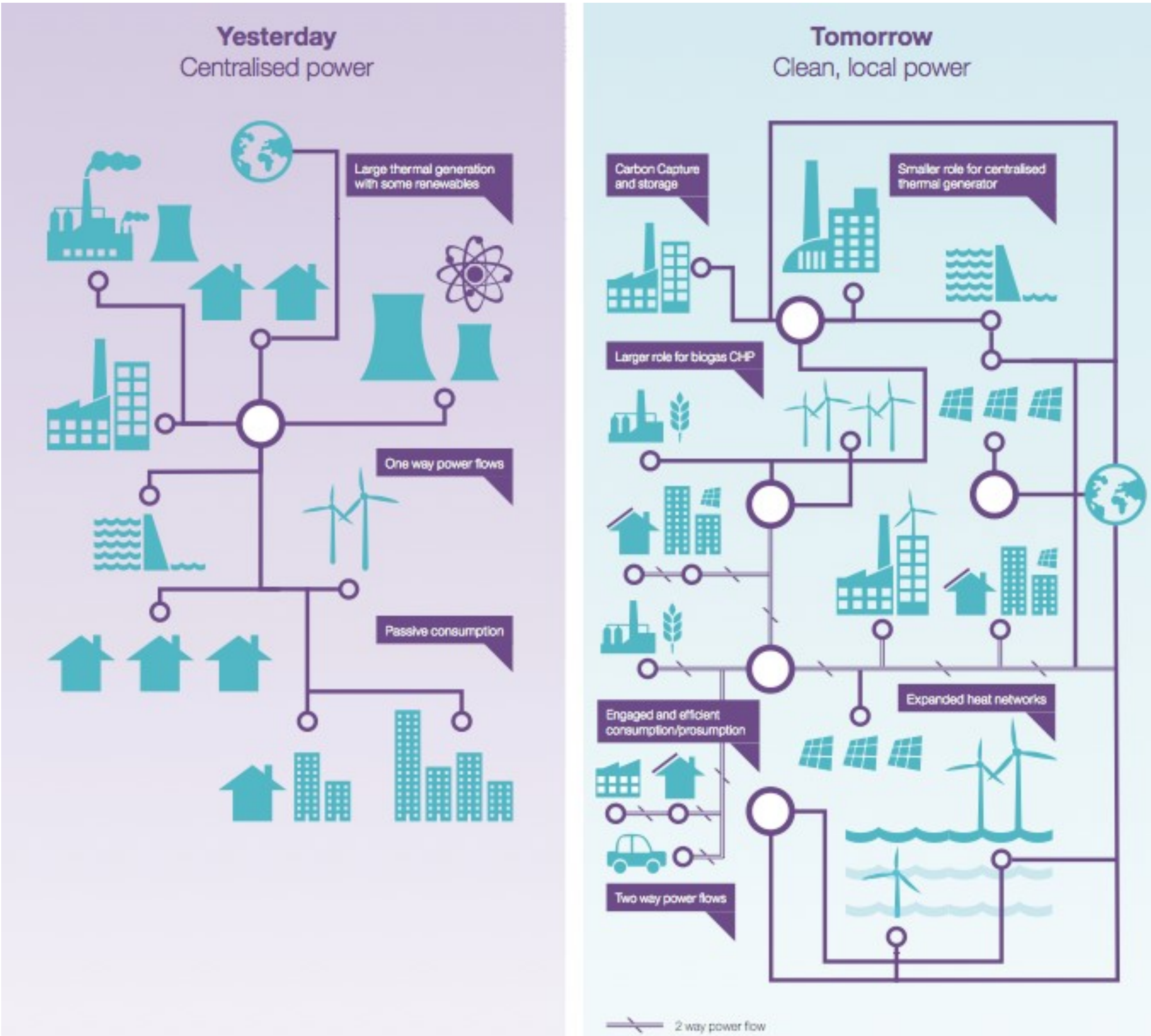
Developing world

- Hard to integrate remote areas without electricity into existing grid
- Maintenance of centralized grid difficult in sparsely populated or unsafe areas



https://www.energy.gov/eere/articles/confronting-duck-curve-how-address-over-generation-solar-energy
http://www.govtech.com/dc/articles/Microgrids-Sustain-Power-During-Natural-Disasters.html
https://www.greenbiz.com/blog/2013/08/01/how-microgrids-can-help-developing-nations-leapfrog-landline

Focus: Integration of small, local sources



How to manage small sources that are difficult to predict?

Cluster into locally controlled microgrids

http://www.theenergycollective.com/roman-kilisek/2210036/power-grid-future-distributed-generation-led-civic-energy-sector
Realising Transition Pathways, Research Consortium ‘Engine Room’

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- **What are microgrids?**
- Advantages and challenges of microgrids
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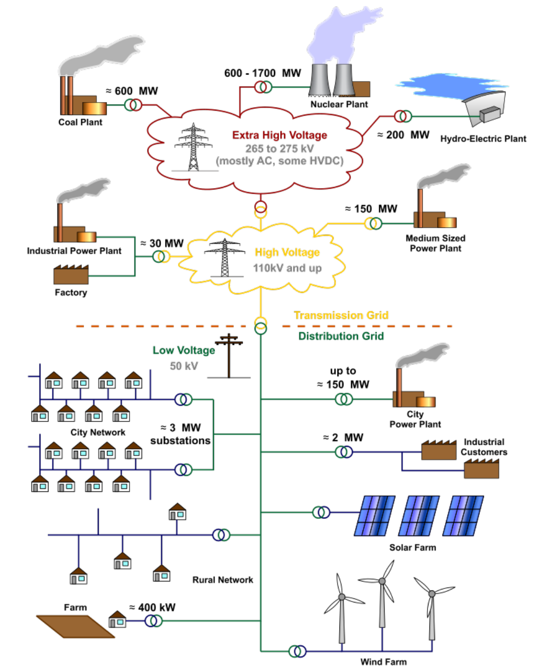
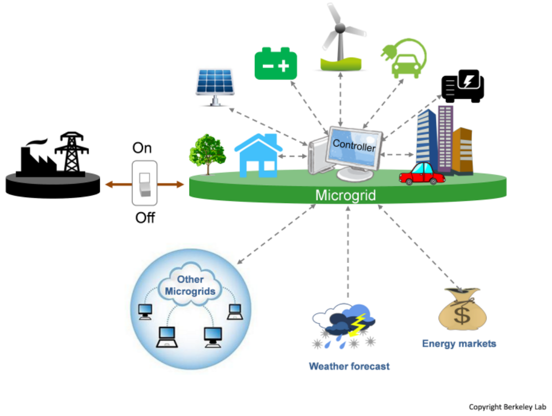
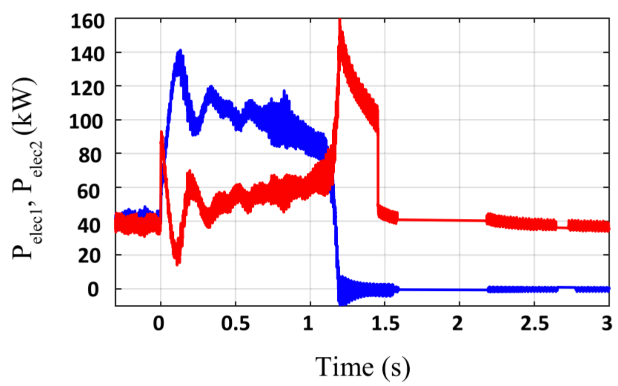
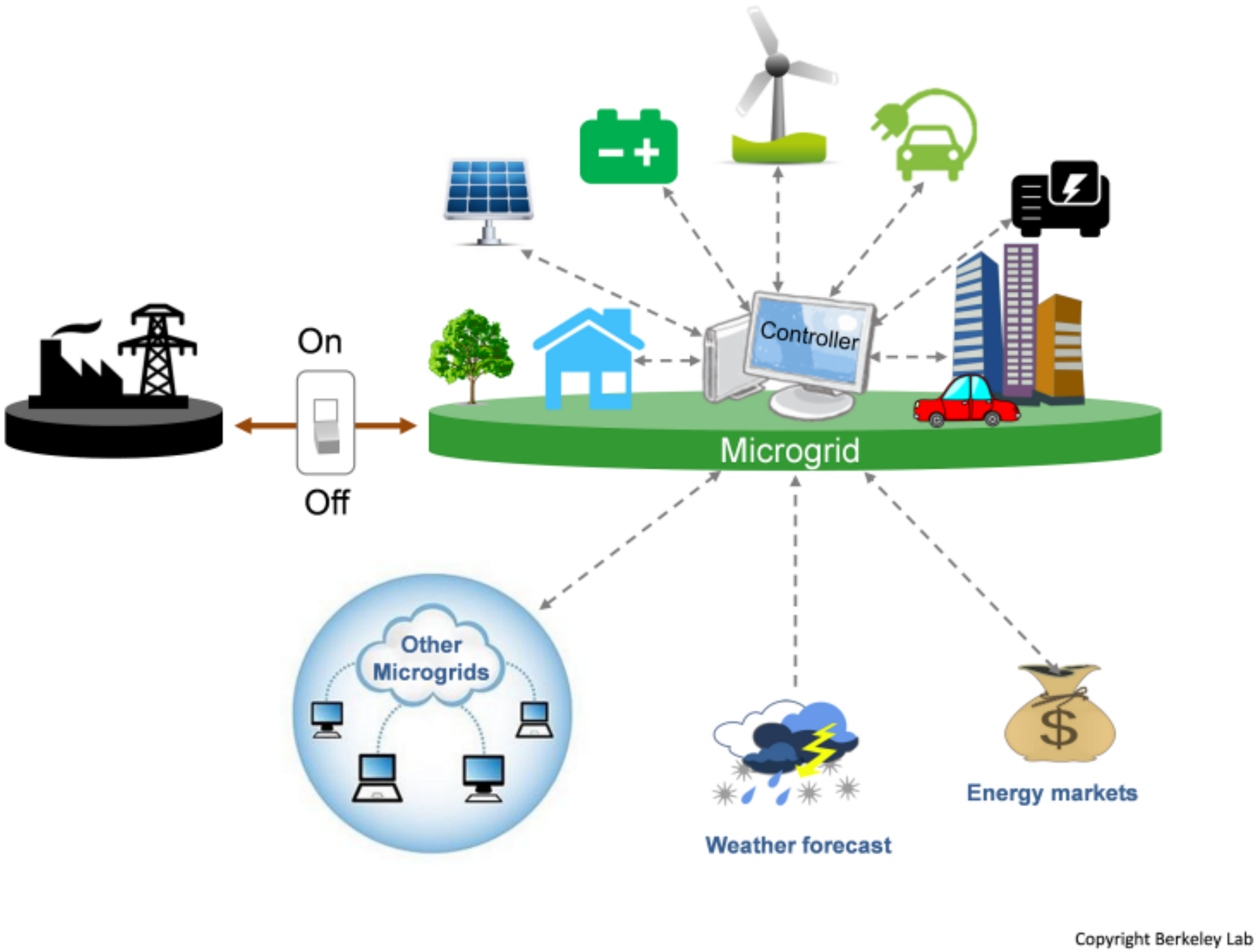






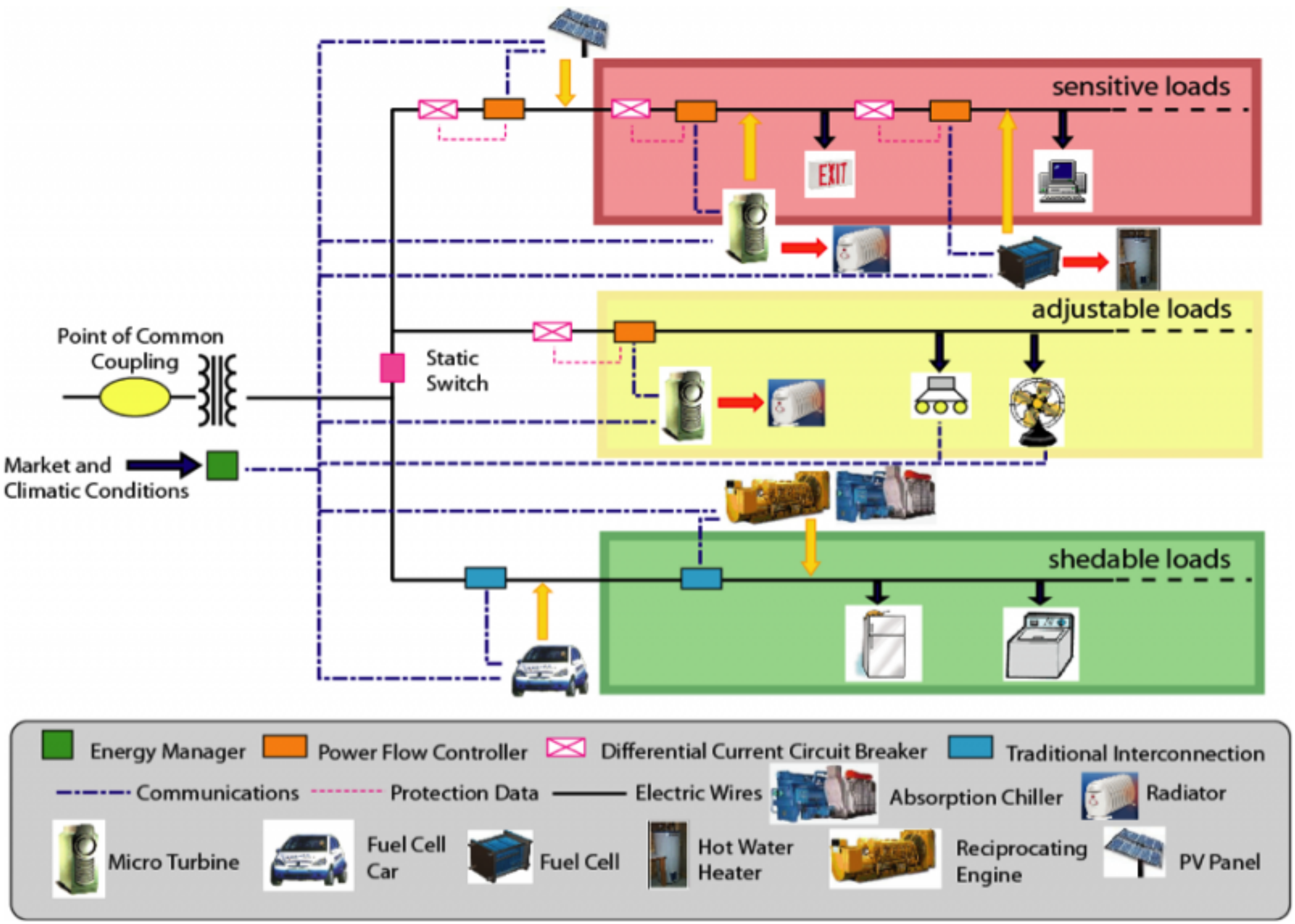
What are microgrids?

“A microgrid is a local energy grid with control capability, which means it can disconnect from the traditional grid and operate autonomously.” [1]



[1] https://www.energy.gov/articles/how-microgrids-work
https://building-microgrid.lbl.gov/about-microgrids

What are microgrids?



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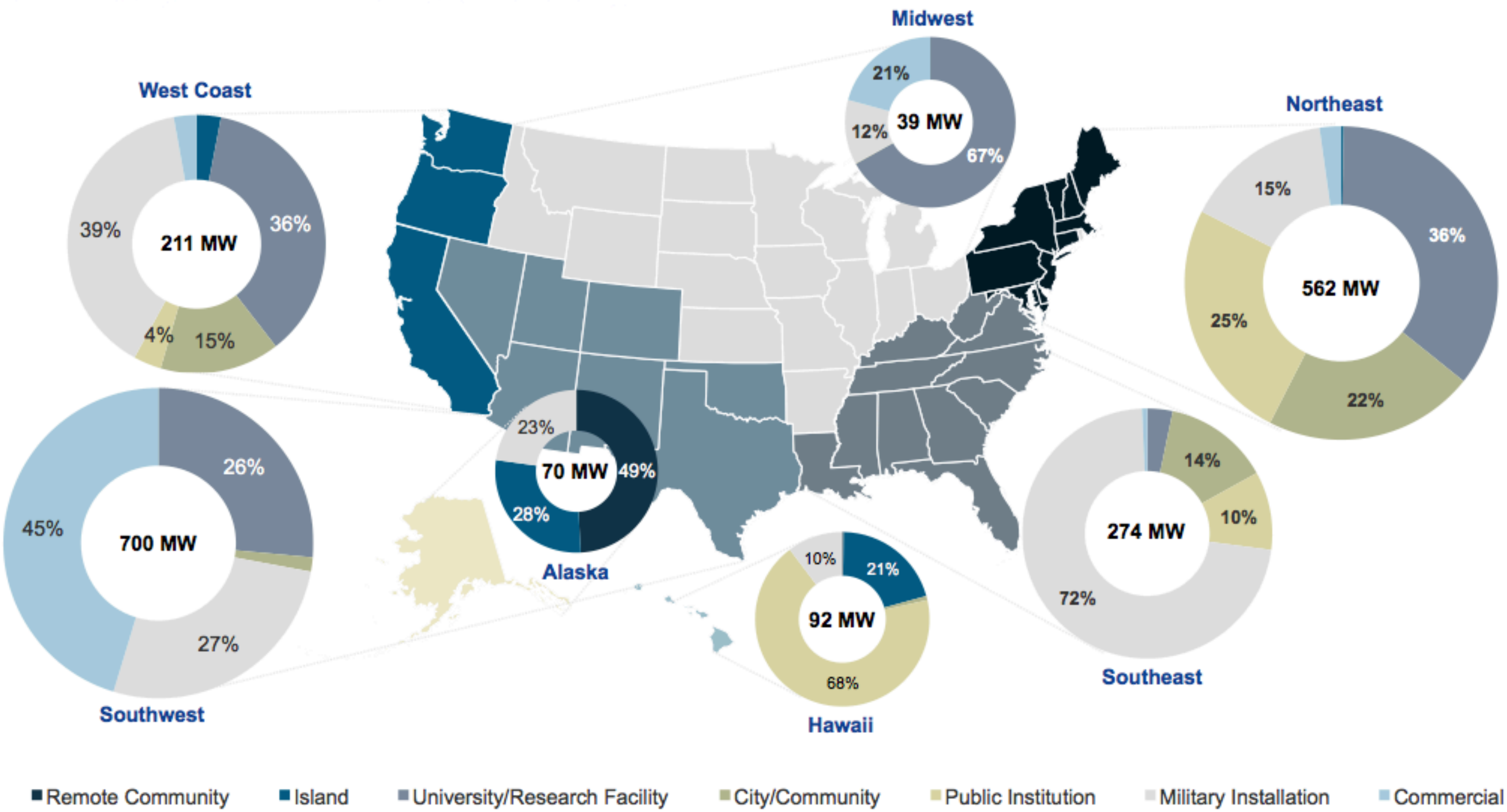
Size and forecast of the microgrid market

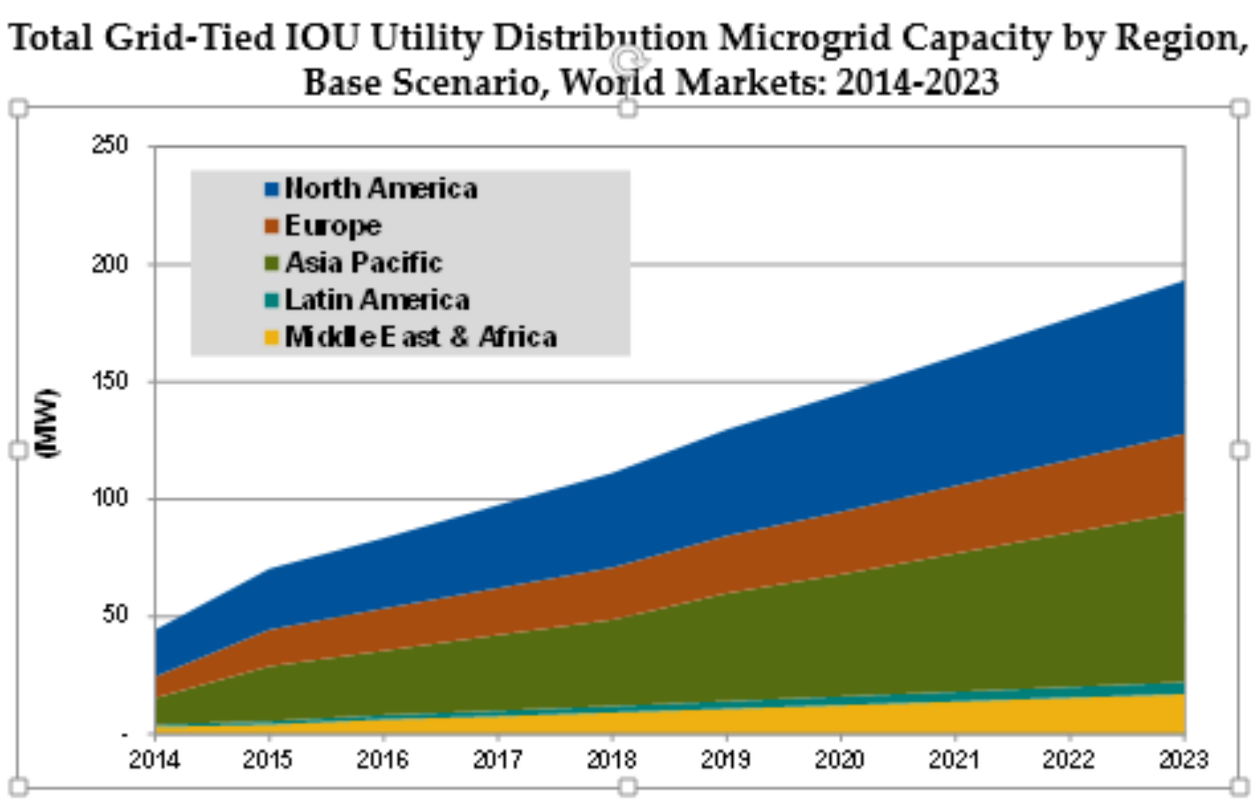
Total microgrid generation capacity by region



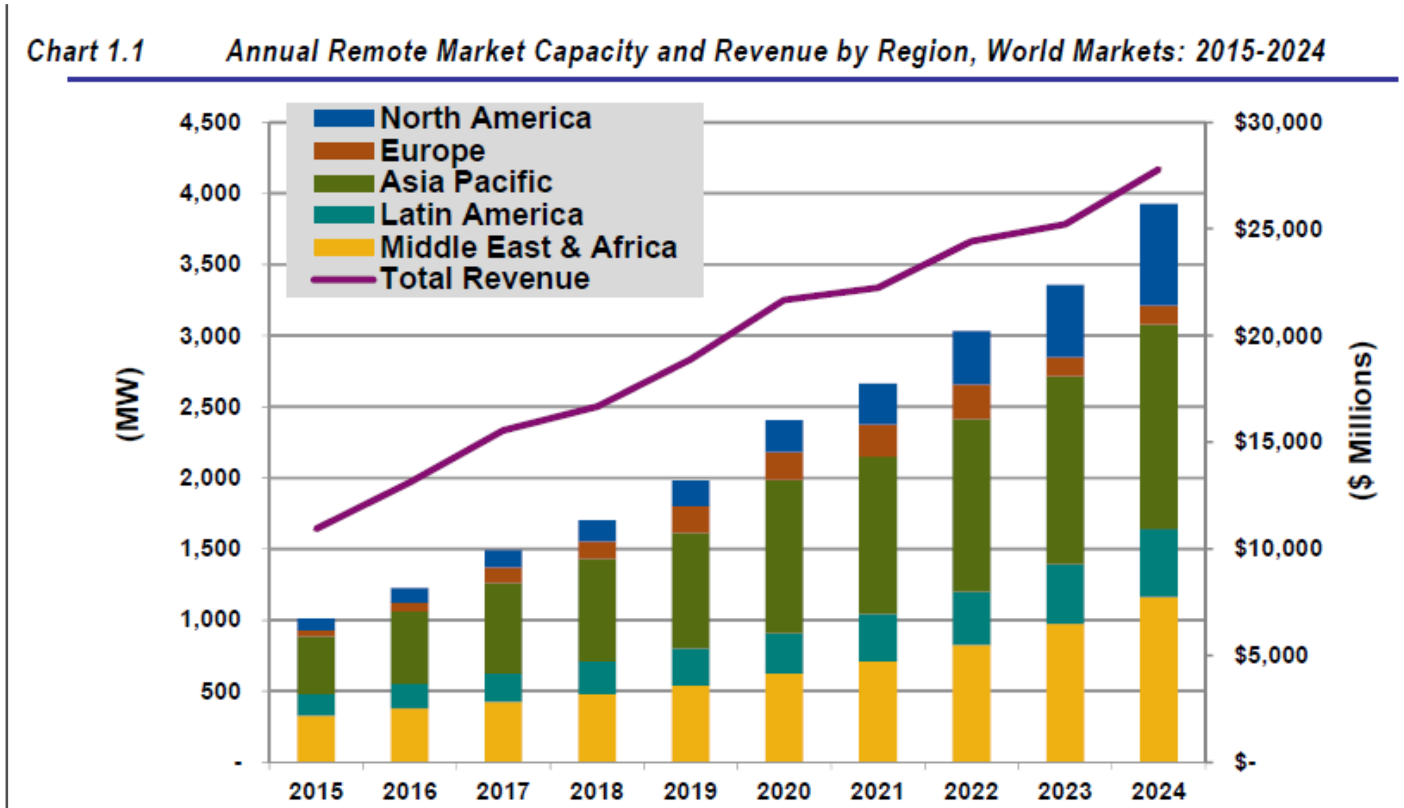
GTM Research
https://www.greentechmedia.com/research/report/north-american-microgrids-2015#gs.Y7KTBxM

Size and forecast of the microgrid market

Grid-tied microgrids



Remote microgrids



Very different numbers depending on how "microgrid" is defined!

Navigant Research
https://microgridknowledge.com/how-fast-is-the-microgrid-market-growing-really/
http://microgridmedia.com/20x-growth-forecast-in-remote-microgrid-and-nanogrid-market/

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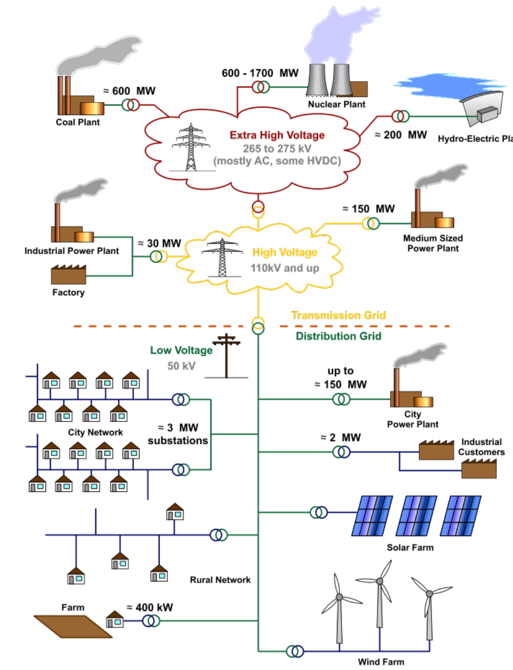

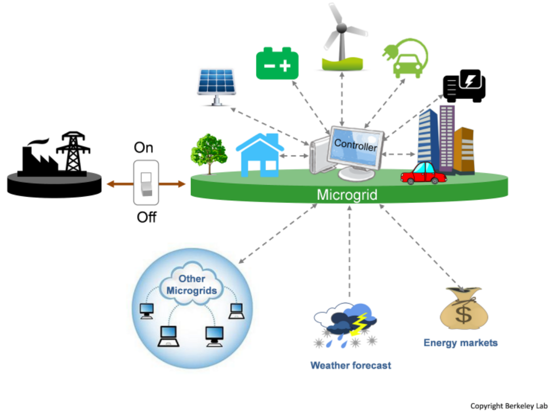

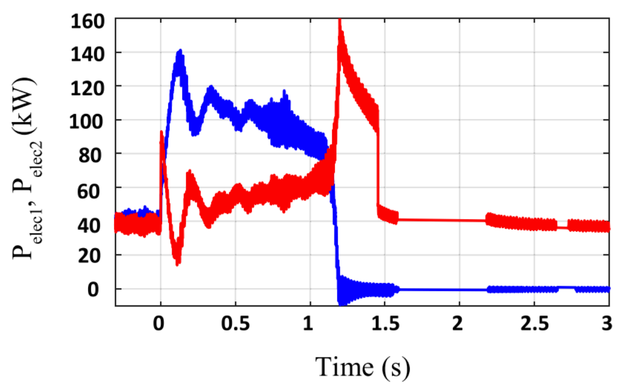

Advantages

- Integration of distributed and renewable energy sources
- Improved energy efficiency and reduction of overall consumption
- Increased end-user participation
- Philosophical aspect: Locally controlled grids lead to wiser / more sustainable technology choices

https://www.generalmicrogrids.com/about-microgrids
Siemens YouTube video

Siemens: Microgrids and community

https://www.youtube.com/watch?v=WKHV5_KYw8k

Challenges

- Control
  - Monitor and control sources in local network, match frequency to macrogrid
  - Predict supply and demand and on/off to macrogrid
  - Communicate with macrogrid
- Status quo
  - Utilities have little interest in losing control over parts of network
- Regulation
  - How to regulate and police relationship between local and global controllers?
  - Pricing: Effective “regressive tax” for owners of local sources

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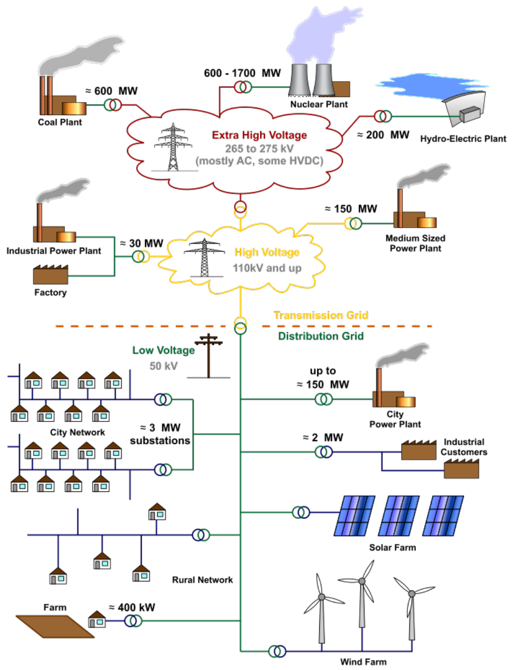
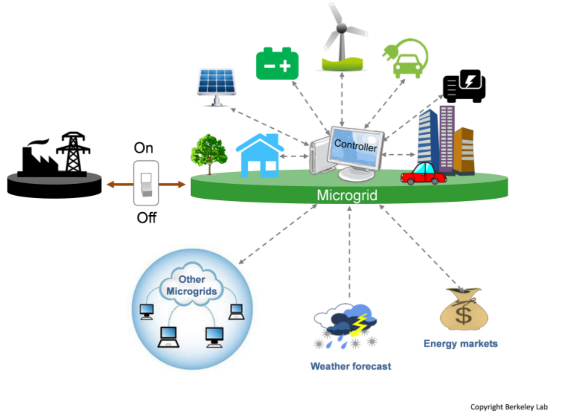
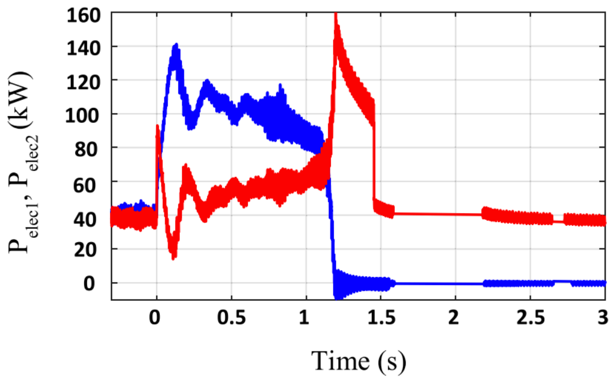






Control challenge:
Preventing collapse of mixed-source microgrid

4566 IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS, VOL. 52, NO. 6, NOVEMBER/DECEMBER 2016

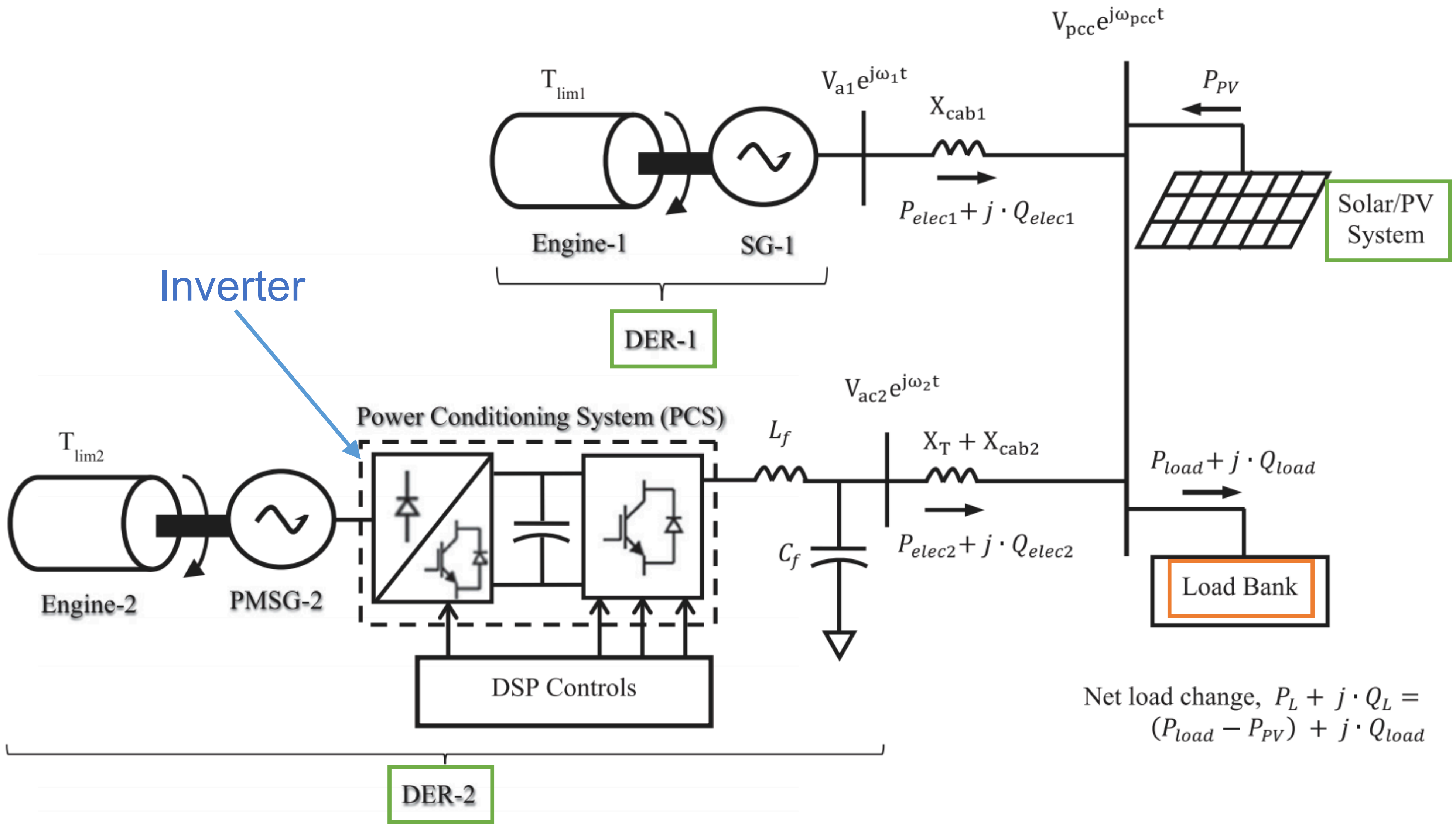
Evaluation of Control Methods to Prevent Collapse of a Mixed-Source Microgrid

Mariana C. Pulcherio, *Student Member, IEEE*, Ajit Anbiah Renjit, *Member, IEEE*,
Mahesh S. Illindala, *Senior Member, IEEE*, Amrit S. Khalsa, *Member, IEEE*, Joseph H. Eto, *Member, IEEE*,
David A. Klapp, *Member, IEEE*, and Robert H. Lasseter, *Life Fellow, IEEE*

- Scenario: Sudden loss of PV generation in islanded condition
- Problem: Cascading collapse of remaining sources
- Solution: Controller ensures sufficient “reserve margin” for each generator

Pulcherio et al. 2016

Control challenge:
Preventing collapse of mixed-source microgrid



Pulcherio et al. 2016

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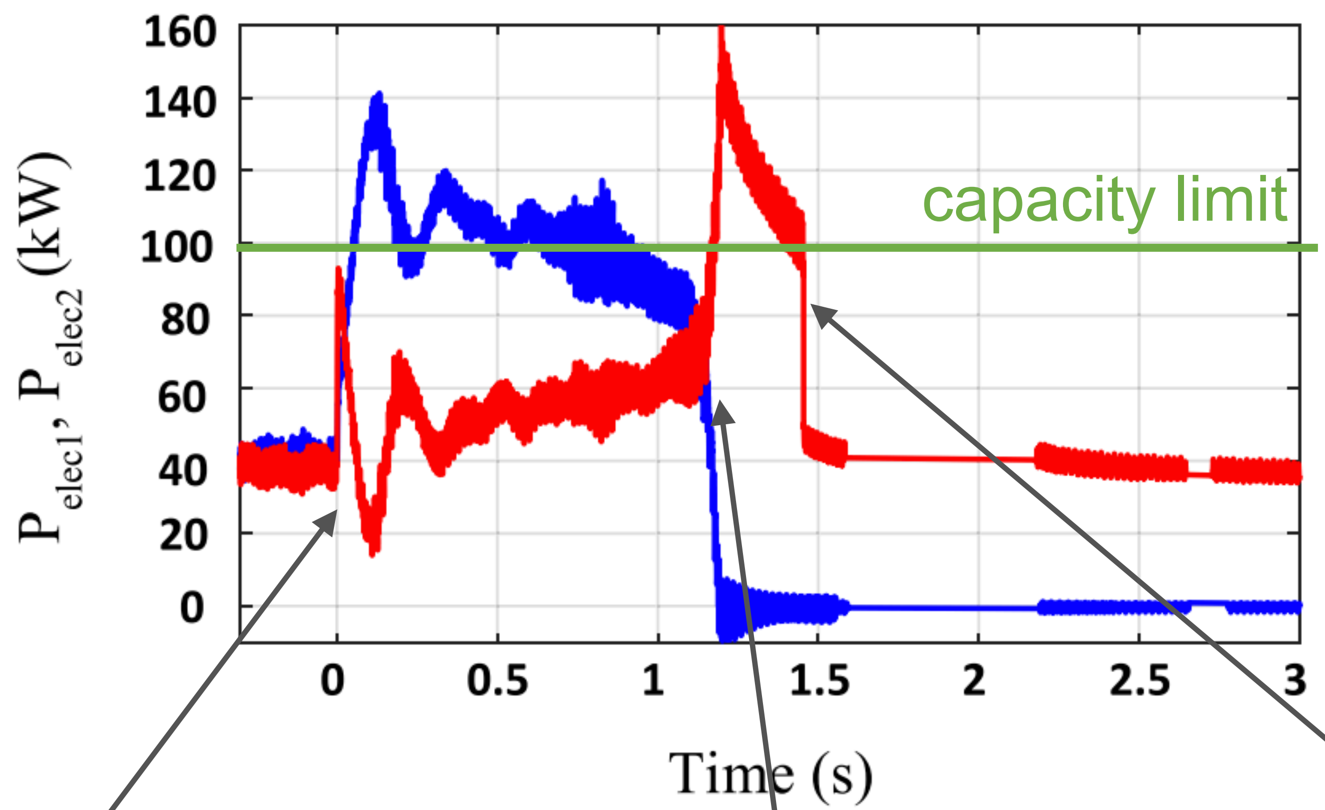

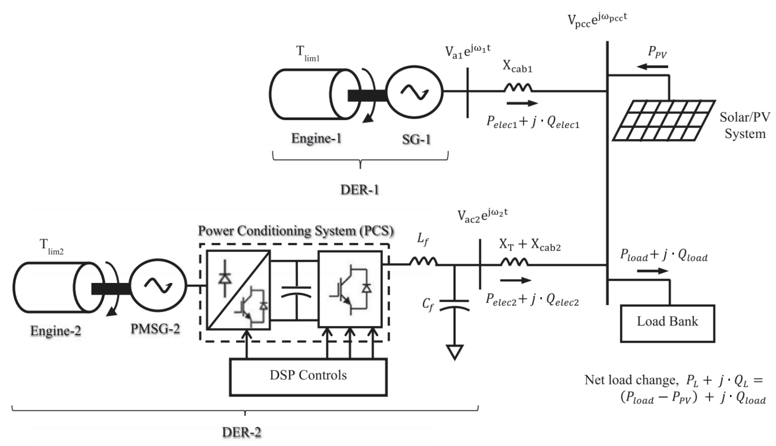

PV generation drops, load changes from 75 kW to 150 kW

DER-2 fails, DER-1 rises beyond its 100 kW capacity

DER-1 fails

- DER-2 responds faster and rises beyond its 100 kW capacity
- Failure of DER-2 cascades to failure of DER-1

➔ **Controller should restrict power output from DER-2**

Pulcherio et al. 2016

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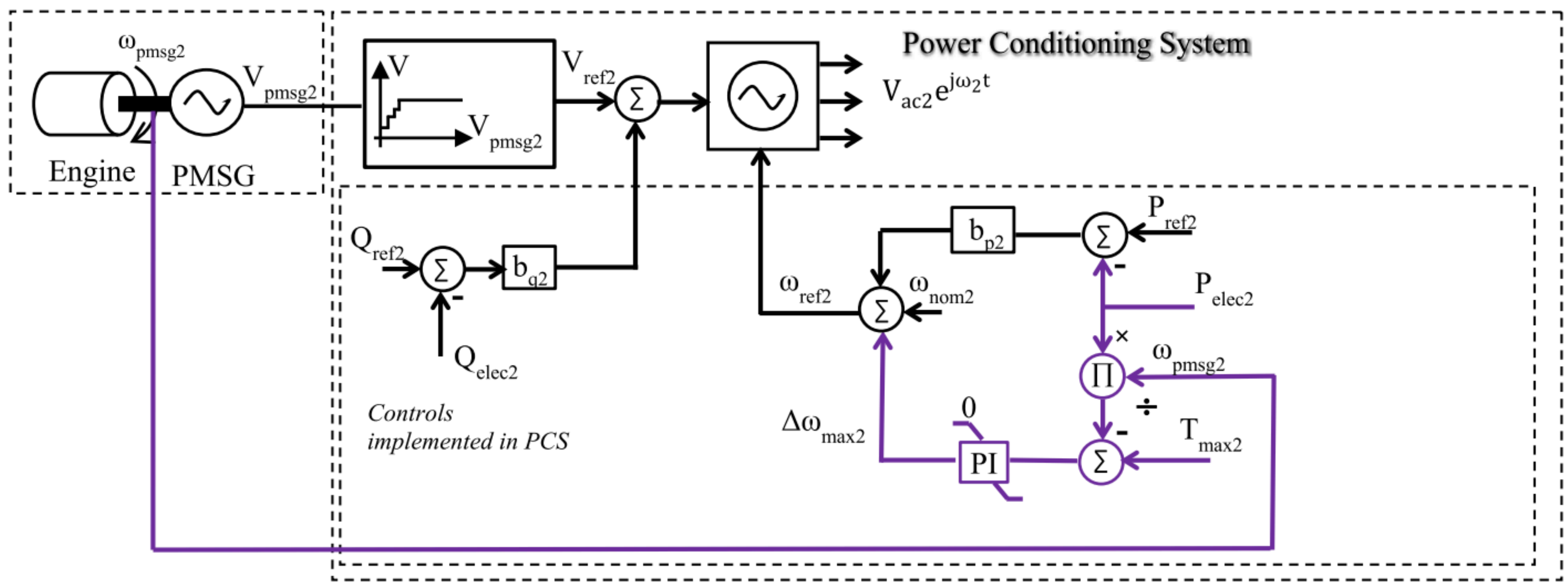
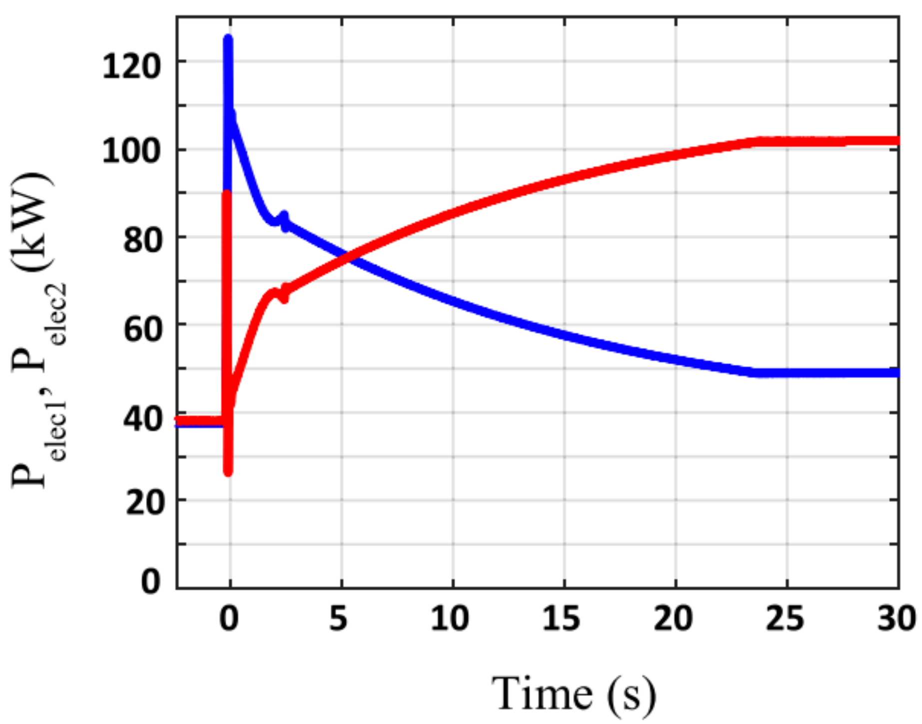
Preventing collapse of mixed-source microgrid





- Torque controller indirectly varies output powers of DER-1 and DER-2
- **Operation stable at all times!**

Pulcherio et al. 2016

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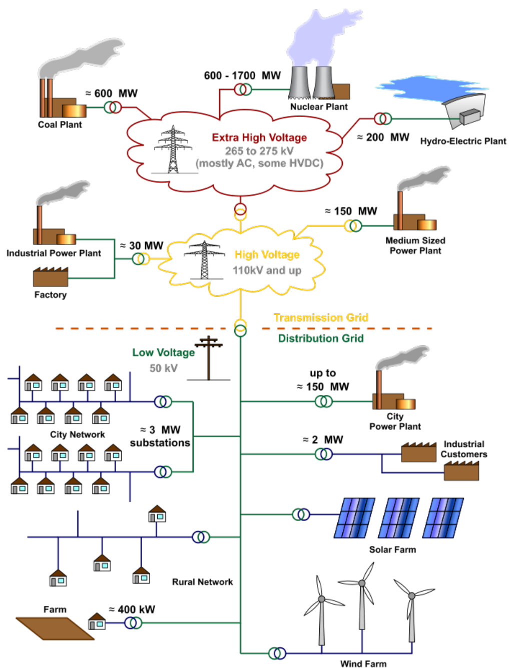
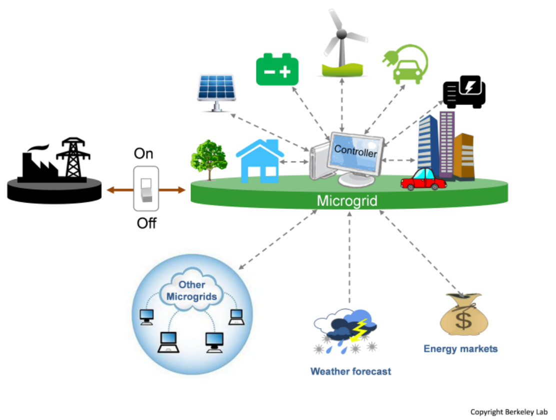
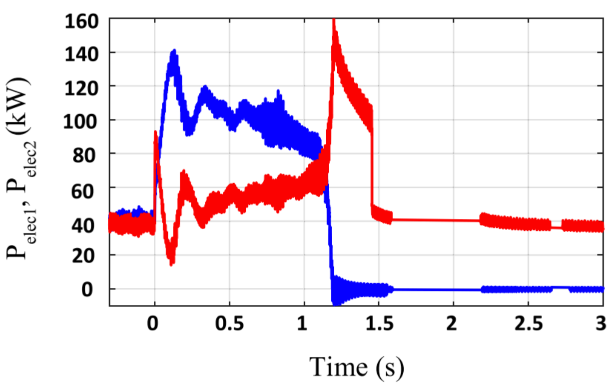






Case study: Santa Rita Jail microgrid

MICROGRIDS AT BERKELEY LAB
BERKELEY LAB
GRID INTEGRATION GROUP • ENERGY STORAGE AND DISTRIBUTED RESOURCES DIVISION

U.S. DEPARTMENT OF ENERGY

Overview

- Location: Dublin, CA
- 4’500 inmate facility
- Relatively flat load, peak demand ~3.0 MW

Technology installed

- 1.2 MW PV system covering most of the cell blocks (installed 2002)
- 1 MW molten carbonate fuel cell (installed 2006)
- 2 MW / 4 MWh Li-ion battery (installed 2006?)
- CERTS microgrid capability - allows for disconnecting from grid and running in island mode

https://certs.lbl.gov/initiatives/certs-microgrid-concept
https://building-microgrid.lbl.gov

Predictions for project

- Construction time: 7 months
- Expected lifetime: 25 years
- Project cost including operation for 25 years and fuel cell maintenance for 13 years: **$6,100,000**
- Expected savings: $264,000/year -> **$6,600,000** over lifetime
- Incentives: **$1,400,000** from California Self-Generation Incentive Program, **$1,000,000** from DoD Climate Change Fuel Cell Program
- Expected payback time with incentives: **14 years**
- Expected savings with incentives over lifetime: **$2,900,000**

But: Unexpected challenge…

Challenge of Santa Rita jail microgrid

Unexpected challenge: Fuel cell has unreliable power output

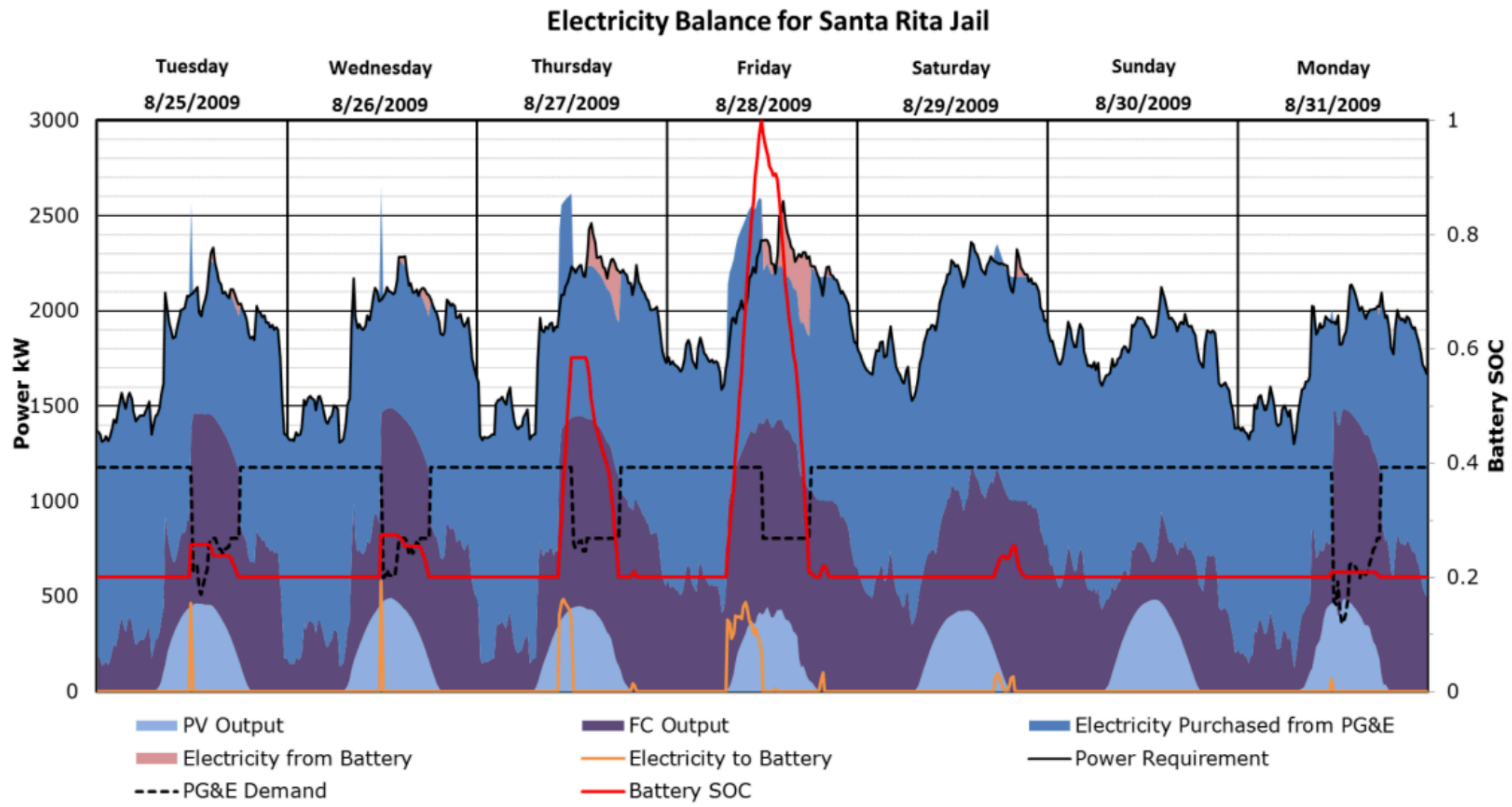
Microgrid Reliability Modeling and Battery Scheduling Using Stochastic Linear Programming

Gonçalo Cardoso[1,a], Michael Stadler[2,3,b], Afzal Siddiqui[4,5,c], Chris Marnay[2,d], Nicholas DeForest[2,e], Ana Barbosa-Póvoa[1,f], and Paulo Ferrão[1,g]

- Battery is only resource that can be controlled to maintain energy balance
- Optimal battery charging/discharging schedule under uncertainty of fuel cell power output
- “The fuel cell has proven unreliable and is frequently out of service”
- Interestingly, PV is much more predictable and PV output is assumed to be perfectly predictable

http://eta-publications.lbl.gov/sites/default/files/lbnl-6309e.pdf
https://building-microgrid.lbl.gov

Optimal battery scheduling



- Fuel cell (FC) output fluctuates over time
- Battery mostly left at minimum charge level to reduce losses
- Result of smart scheduling: Potential cost savings >6%

Unclear how actual savings compare to case study

http://eta-publications.lbl.gov/sites/default/files/lbnl-6309e.pdf

Other examples for microgrids

UT Austin, Texas

- Largest microgrid in the US (135 MW)
- Provides 100% of power for campus
- 99.9998 percent reliability over the last 40 years

Alcatraz Island

- 400 kW solar, combined with diesel generators
- Before, pure diesel generation polluted air in popular tourist destination

https://www.greenbiz.com/blog/2014/07/18/how-university-texas-runs-largest-microgrid-us
https://microgridknowledge.com, https://share.america.gov/alcatraz-one-of-the-largest-microgrids-in-u-s/

Conclusion

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