AC OPF-enabled decarbonization for reliable and resilient service

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IEEE PES General Meeting, Orlando, FL, July 17-21, 2

Panel on Many uses of AC Optimal Power Flow in the Changing Industry

Presentation number 23PESGM3888

Societal objectives of electricity services

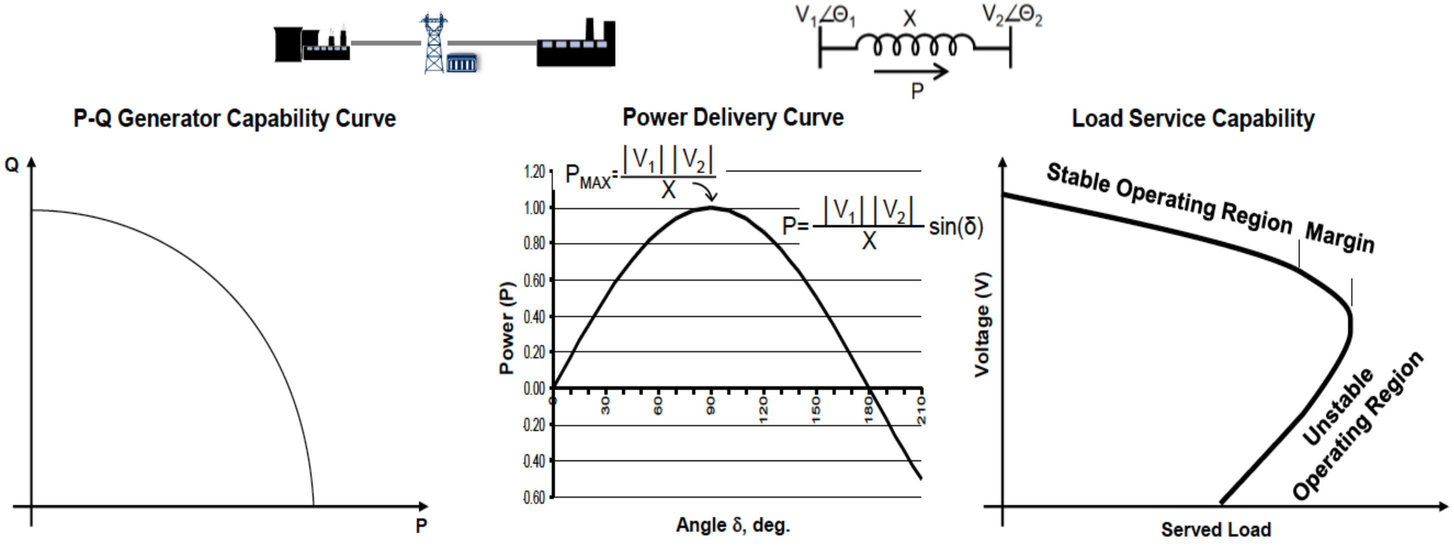
Decarbonized-- Cost-effective -- Reliable/Resilient

- Meeting decarbonization objectives is disruptive to today's operating and planning practices

--deliver clean power along different electrical and geographic paths (flexible grid utilization ?)
--do it by observing NIMBY constraints
--account for customers' preferences
--multiple, often conflicting performance criteria (cost-effective, reliable/resilient)
**All else equal, AC extended OPF makes huge difference in the ability to utilize the grid in new ways (disruptive software needed; must make the case that it matters)

Electricity provision today*

- Top down centralized dispatch and control of large-scale power plants to:
- Task 1) supply predictable system demand;
- Task 2) Compensate predictable transmission losses;
- Task 3) Schedule generation so that there are no ``congestion" delivery grid problems;
- Task 4) Have sufficient regulation reserve to regulate frequency and voltage deviations caused by hard-to-predict slow power imbalances;
- Task 5) Have sufficient security reserve to supply predictable demand reliably even during the worst case (N-1/N-2) outages;
- Task 6) Provide service during extreme events (N-k, k>>2) in a resilient way



Constraints
P (real power), Q (reactive power), V (voltage), R (ramp rate)
Controls
P (real power), V (voltage), R (ramp rate)

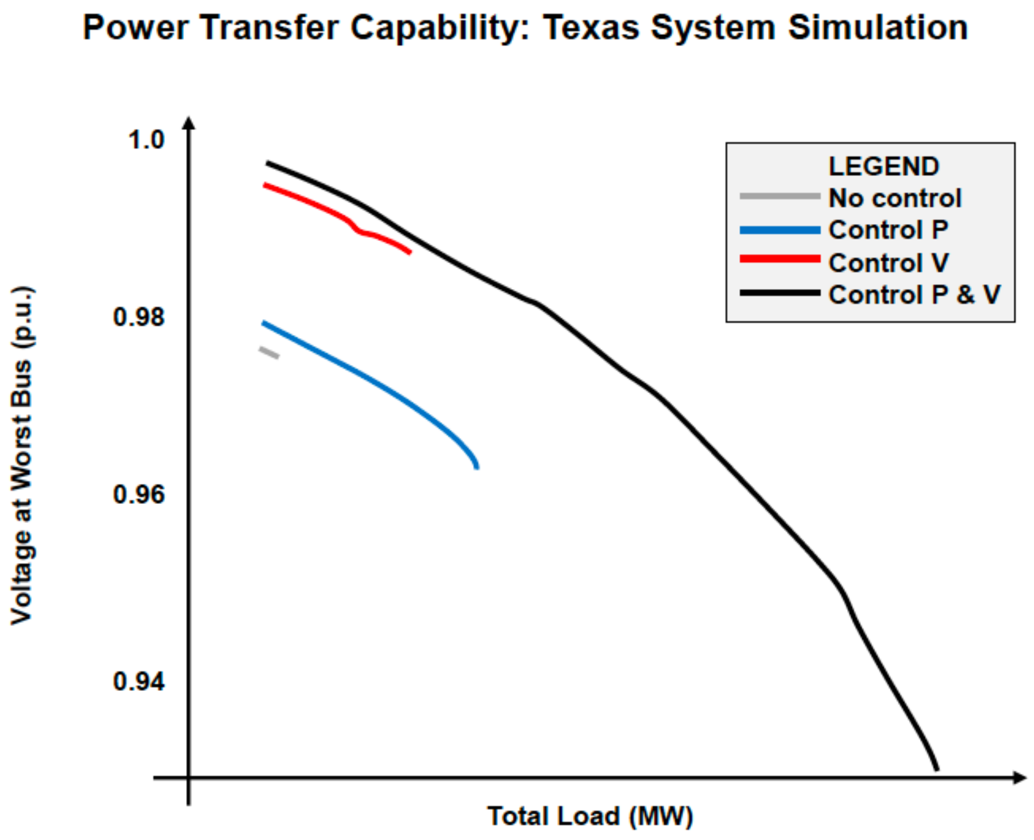
Constraints
P_{MAX} (electrical limit), P_{TH} (thermal limit)
Controls
X (reactance), V (voltage)

Constraints
Load Served
Controls
L (load served)

Ilić, Marija, and Francisco Galiana. "Power systems operation: old vs. new."Power Systems Restructuring. Springer, Boston, MA, 1998. 15-107.

AC OPF ``congestion” management

- Congestion—both thermal and electrical (optimizing voltages on regulating equipment – the key)
- The need to have ***ACOPF-based scheduling*** instead of ***AC power flow-based analyses*** tools
- Adjustments are supposed to work for both “normal” and “abnormal” conditions. Tasks 5 and 6 can also be enhanced significantly by using AC OPF*
- ACOPF-based mitigation for non-time-critical abnormal conditions is very similar to the one with normal conditions



**Ilic, M., Ulerio, R. S., Corbett, E., Austin, E., Shatz, M., & Limpaecher, E. (2020). A Framework for Evaluating Electric Power Grid Improvements in Puerto Rico.*

Ilić, Marija, Sanja Cvijić, Jeffrey H. Lang, Jiangzhong Tong, and Diran Obadina. "Operating beyond today's PV curves: Challenges and potential benefits." In *2015 IEEE Power & Energy Society General Meeting*, pp. 1-5. IEEE, 2015.

Resilient and reliable scheduling

From voltage constrained decision making (DCOPF + AC power flow) to coupled AC Optimal Power Flow

- Given an existing system, how to operate new power plants without experiencing power delivery problems.
- Given an existing system, how much new, renewable, generation to build and at which locations.
- Assess the effect of different pricing rules for integrating renewable resources on long- and short-term economic efficiency and the ability to recover capital investment cost.

ACOPF is the key software for co-optimizing power generation and voltage settings; **increased maximum power transfers**

Why is DCOPF insufficient?
With increased renewable penetration, it no longer is possible to dispatch real power with DCOPF well enough without optimizing the voltage settings

* Cvijić, Sanja, Marija Ilić, Eric Allen, and Jeffrey Lang. "Using extended ac optimal power flow for effective decision making." In *2018 IEEE PES Innovative Smart Grid Technologies Conference Europe (ISGT-Europe)*

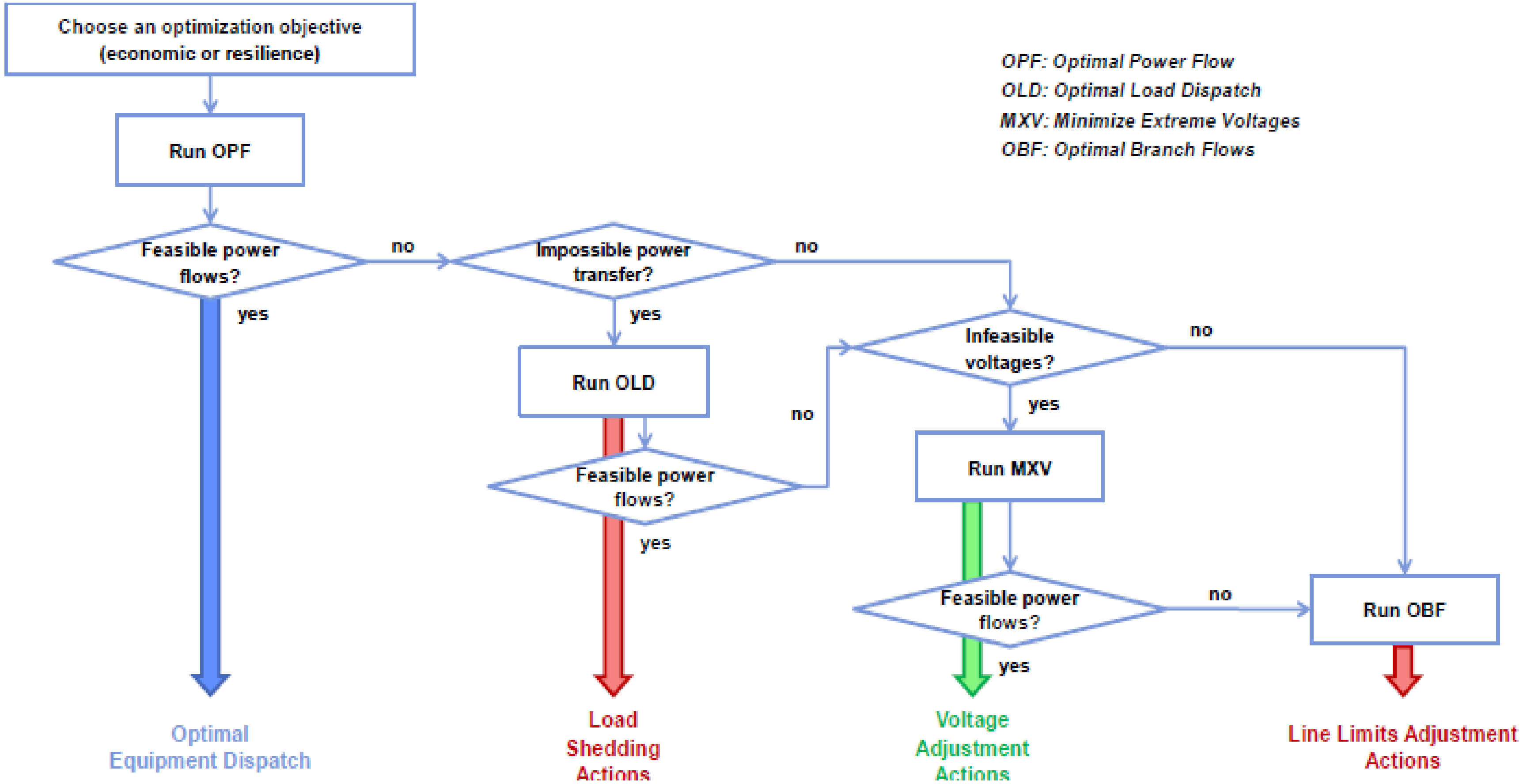
From analysis to optimization

- Having the ability to find a solution within specified network and hardware constraints
- Having the ability to optimize with respect to all available decision variables, such as real power generation, demand, and T&D voltage-controllable equipment
- Providing as part of its output optimization sensitivities
- Providing support of effective resource management according to several optimization objectives
- ***Providing as part of its output LMPs***, which are sensitivities of the performance objective with respect to power injection change at each node in the network

$$\mathrm{LMP}_i = \frac{\delta J}{\delta P_i}$$

Ilić, Marija, Sanja Cvijić, Jeffrey H. Lang, and Jiangzhong Tong. "Optimal voltage management for enhancing electricity market efficiency." In *2015 IEEE Power & Energy Society General Meeting*, pp. 1-5. IEEE, 2015.

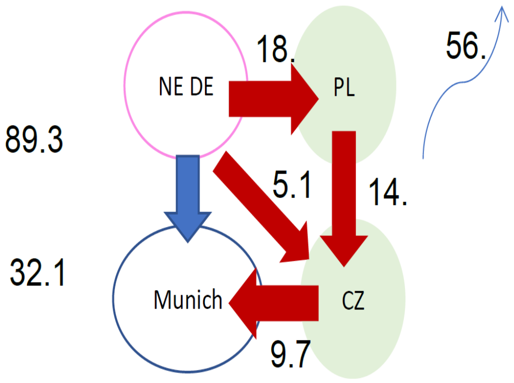
AC-XOPF—robust computing for managing performance



Adaptively switching between different performance objectives. This is essential for reconciling reliability and efficiency when system conditions/topology change significantly

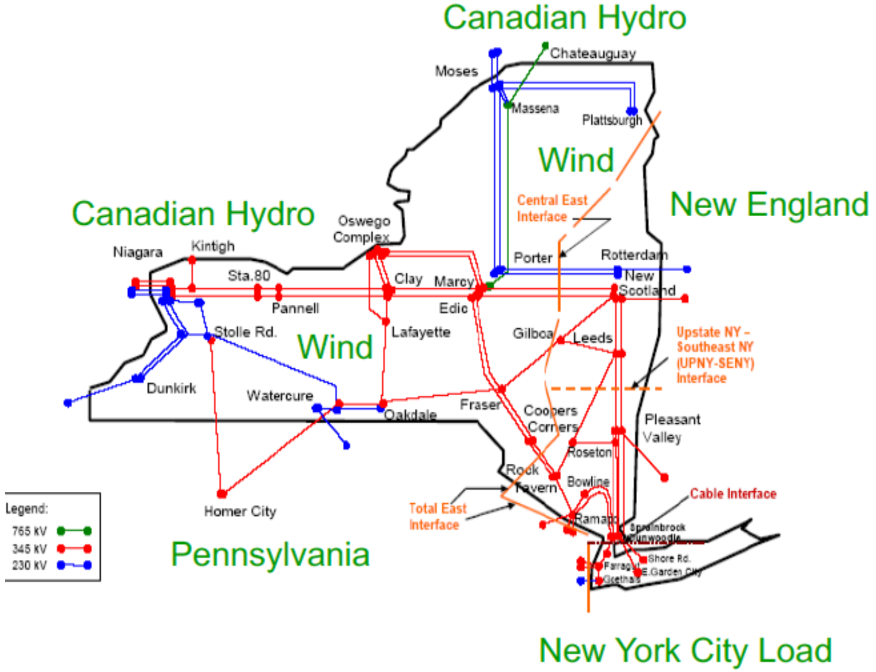
If adopted, it will be successful (demonstrations up to date, normal operations)

Wind power delivery from NW Germany to Bavaria

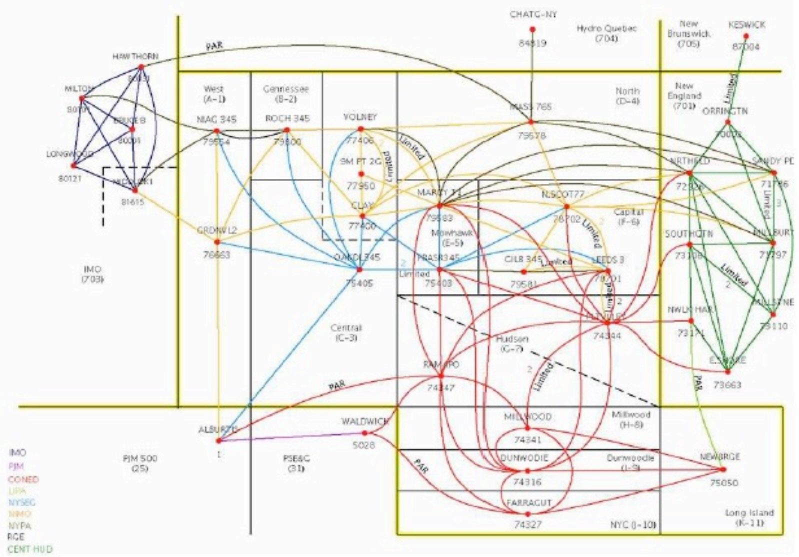


With current grid control
89.3 GW generated
32.1 GW delivered

With DyMonDS
30 GW generated
23 GW delivered



Complex electric energy system in the Northeast (NPCC)



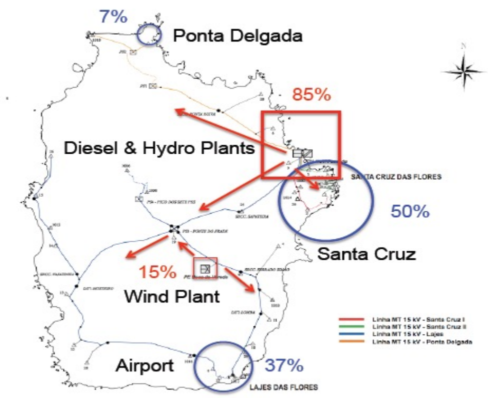
Limits on moving power "around" area
Lack of resilience to climate, cyber, operator/equipment
Failure to engage "campuses" and small DERs as iBAs
No integration across systems (electricity, nuclear, gas, hydrogen?)

- Enabling 1GW clean power transfer from Niagara to NYC
- Seamless integration of DERs

Marija Ilic and Jeffrey Lang, **VOLTAGE DISPATCH AND PRICING IN SUPPORT OF EFFICIENT REAL POWER DISPATCH, NETSS** Final Report, **NYSERDA Project # 10476, 2012.**

Enables delivery of changing generation mix: From dirty to clean; less expensive

100% green Azores Islands, Portugal



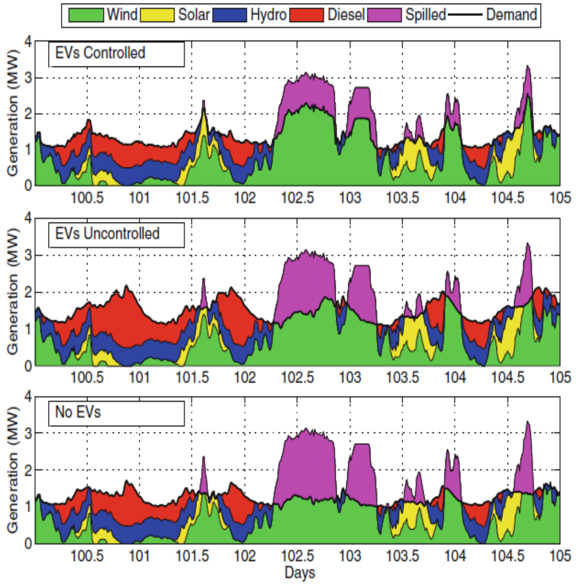
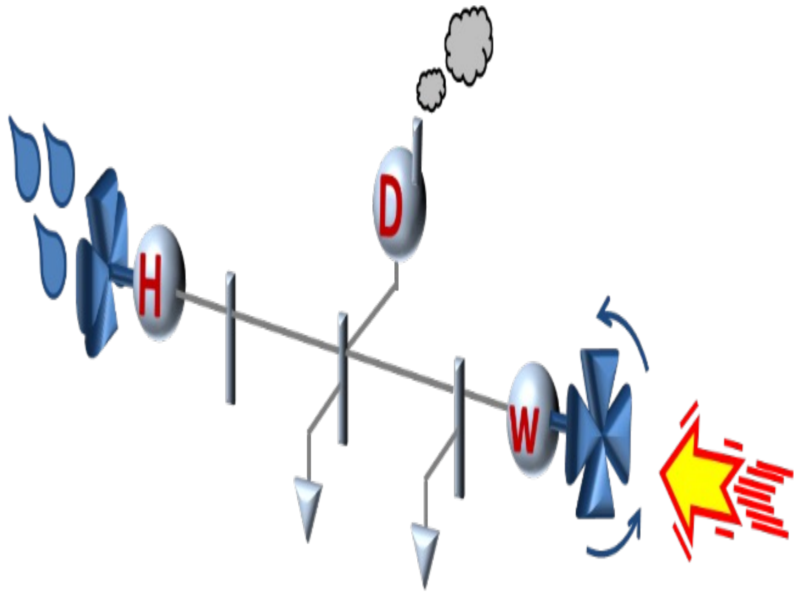


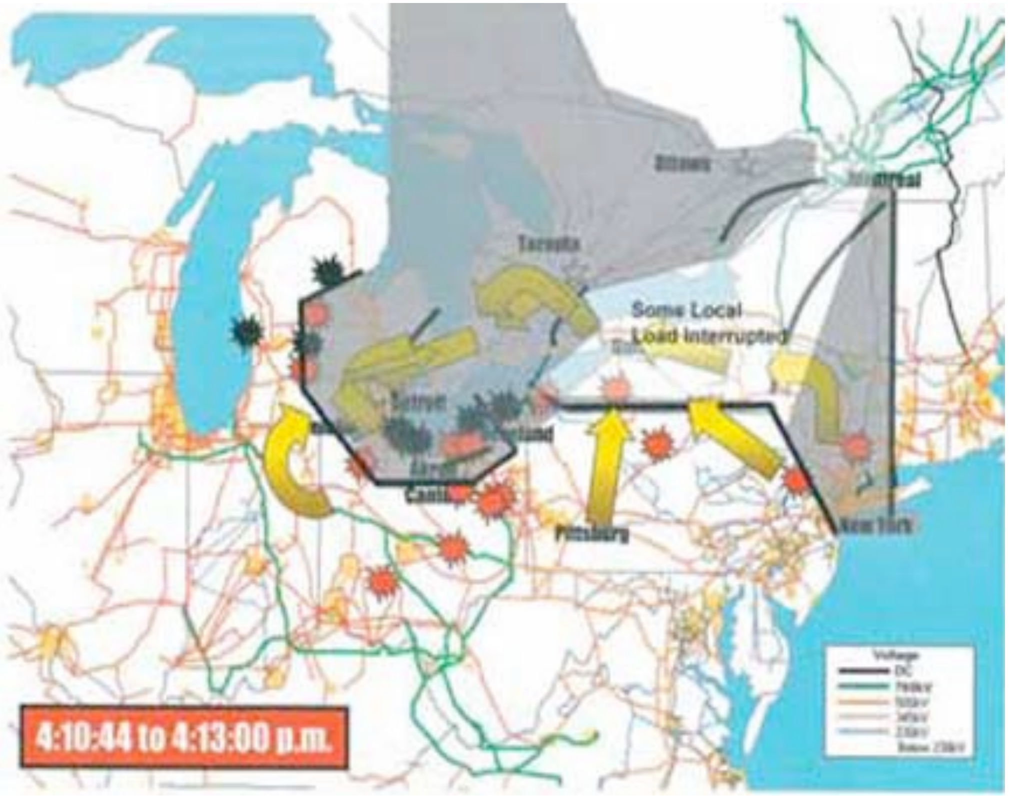
Fig. 11.10 Use of different generation types for a period in spring with 1,000 EVs in different scenarios for the case with moderate wind and solar



- From using >200$/MWh fossil fuel to 88/MWh levelized wind power
- Enabled demand participation ; Real data given to us by the EDA

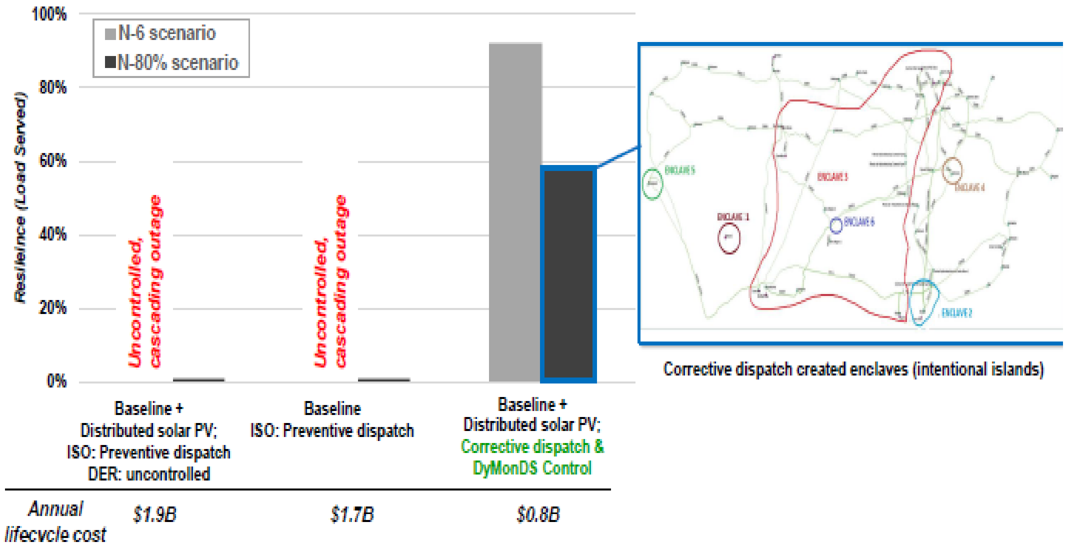
https://books.google.com/books?hl=en&lr=&id=4X1CAAAAQBAJ&oi=fnd&pg=PR7&dq=ilic+azores&ots=OvqMVVb8rH&sig=l4j5Tm3N3kTZNOo_P-t1l58bgoI

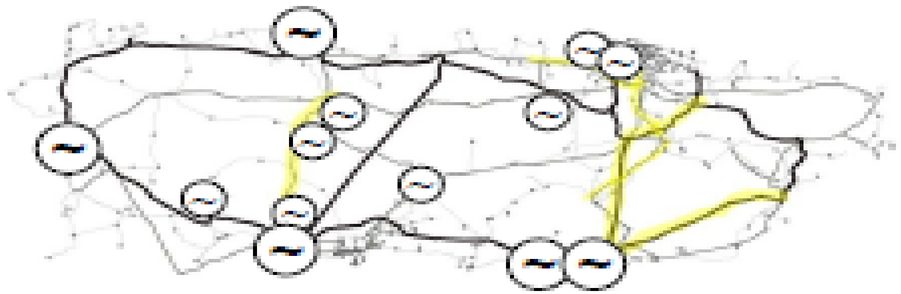
Reliable and resilient power delivery during extreme events; preventing wide-spread blackouts



Blackout 1970s through 2003 could have been prevented

https://ieeexplore.ieee.org/abstract/document/1519724/?casa_token=G2NS7oba8PcAAAAA:9A3k4cdEWvqBeeYKiP4p8o7PdOAxVbGjd0BsCINRRRi-dfw96esyP-f2-e5hGKJ3THU6L0HP





N-6 outage scenario

Potential for dramatic improvements to Puerto Rico grid: 40-60% load service, even after catastrophic damage; 50% lower energy costs

http://www.ll.mit.edu/sites/default/files/publication/doc/2020-07/a-framework-for-evaluating-electric-power-grid-improvements-in-puerto-rico-ilic.pdf