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Understanding Networks
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Power and Puerto Rico

Most Puerto Rican families have been without electricity since Hurricane Maria devastated the island over two months ago[1]. After the governor of Puerto Rico cancelled the first $300 million contract with Whitefish Energy to rebuild the island's power grid, other power providers stepped in to begin restoring electricity[2].

These alternative providers include Sonnen, a German battery and solar power company[3], and Tesla, an American technology company best known for its electric cars[4]. Their work in Puerto Rico is noteworthy for both political and technical reasons: it is rare for private companies to build public infrastructure without government contracts, and both projects rely on the use of batteries as long-term, large-scale power storage.[5]

Incorporating batteries and alternative sources of energy (such as solar) into a power grid would fundamentally alter how electricity is generated and distributed. The work being done in Puerto Rico could be expanded to provide much-needed improvements to existing electrical grids around the world. In order to understand the global potential of Sonnen and Tesla's work in Puerto Rico, we'll begin by exploring how the power grid works in the continental United States today.

The Continental Grid

The existing infrastructure that powers our homes and businesses relies heavily on bureaucratic cooperation. In the U.S., thousands[6] of power plants generate electricity from a variety of energy

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[1] Córdova, A. L. (2017, November 20). Two months later: Puerto Rico doesn't have power, education or economy running again. Retrieved November 27, 2017, from http://thehill.com/opinion/energy-environment/361211-two-months-later-puerto-rico-doesnt-have-power-education-or

[2] Peters, A. (2017, November 07). Can Puerto Rico Be The Model For A Renewables-Powered Energy System? Retrieved November 27, 2017, from http://www.fastcompany.com/40490241/can-puerto-rico-be-the-model-for-a-renewables-powered-energy-system

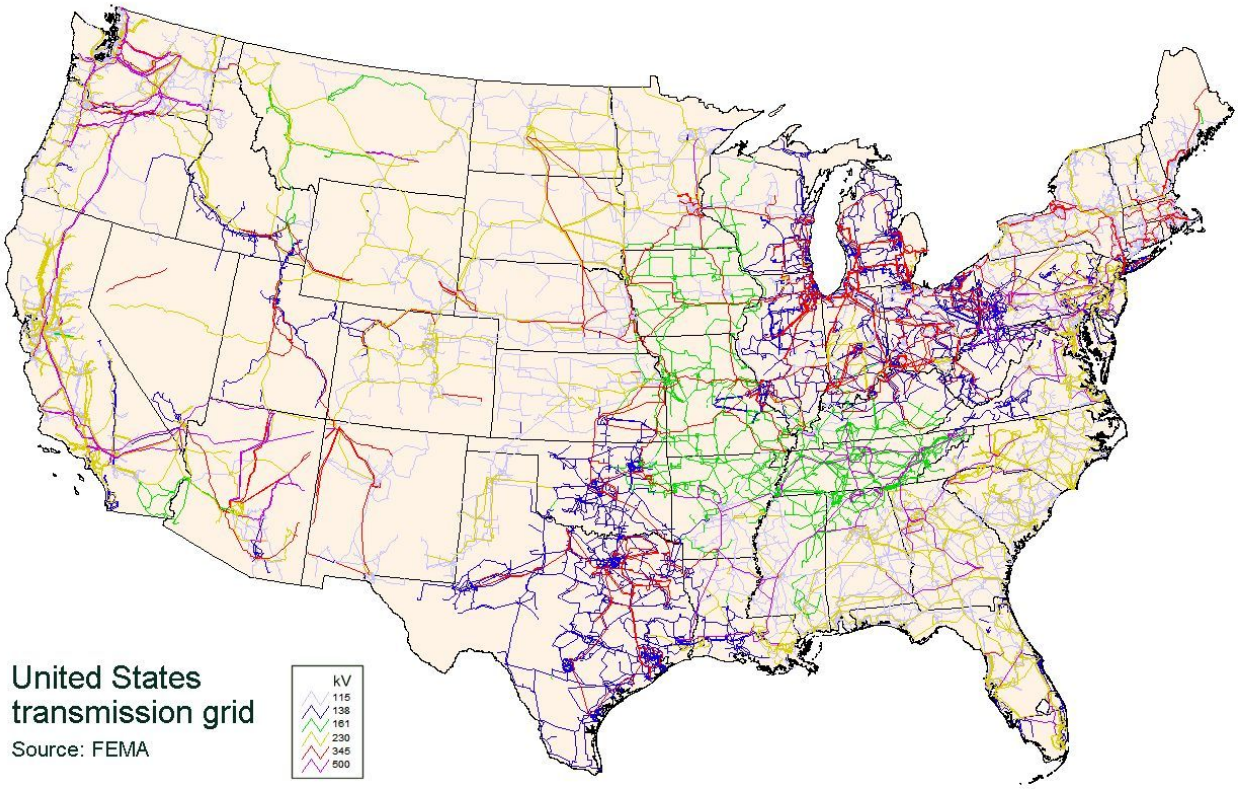
[3] https://sonnen-batterie.com/en-us/start

[4] https://www.tesla.com

[5] Novak, J. (2017, October 10). Elon Musk's offer to rebuild Puerto Rico's electricity grid is a game-changer. Retrieved October 18, 2017, from https://www.cnbc.com/2017/10/09/elon-musks-offer-to-rebuild-puerto-ricos-electricity-grid-is-a-game-changer-commentary.html

[6] U.S. Energy Information Administration - EIA - Independent Statistics and Analysis. (n.d.). Retrieved October 18, 2017, from https://www.eia.gov/tools/faqs/faq.php?id=65&t=2

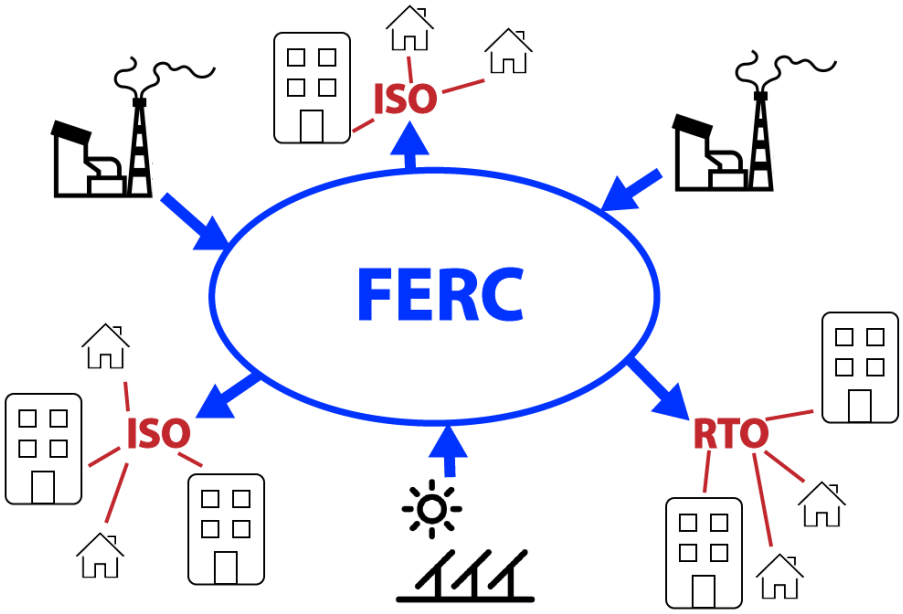
sources including fossil fuels (65%), nuclear reactions (20%), hydro (6.5%), wind (5.6%), biomass (1.5%), solar (0.9%), and geothermal (0.4%)[7]. This electricity then enters a national transmission grid regulated by the Federal Energy Regulatory Commission (FERC). The transmission grid is responsible for bringing electricity to the contiguous United States.



Although the FERC provides electricity on a national scale, it is not directly responsible for powering each and every home and business in the U.S. That privilege falls to regional transmission operators (RTOs) and independent system operators (ISOs), non-governmental organizations (usually non-profit) that exist to provide non-discriminatory transmission services to different geographic regions: sometimes one state, sometimes several[8].

[7] "Electricity in the United States." *Electricity in the United States - Energy Explained, Your Guide To Understanding Energy - Energy Information Administration*, www.eia.gov/energyexplained/index.cfm?page=electricity_in_the_united_states

[8] (2017, May 11). Retrieved October 18, 2017, from https://www.ferc.gov/industries/electric/indus-act/rto.asp



One of the trickier steps in this collaboration is regional load forecasting, in which RTOs and ISOs anticipate how much energy their consumers will need in the future[9]. This is necessary because power plants must know how much energy to produce. The RTOs and ISOs are connected by one national grid, and like any electrical circuit, this grid cannot store excess energy. If energy is permitted to build up in a circuit, eventually the circuit's components will overheat and melt or explode.

Of course, the national grid has safety mechanisms in place to prevent overheating. Like the fusebox in your home, sections of the grid will shut down when overwhelmed with excess power, thus causing blackouts. So the FERC, the various RTOs and ISOs, and the thousands of power plants scattered throughout the country work together to keep the national grid supplied with just enough energy to go around, based on predictions that must be made years in advance. It's a miracle blackouts aren't more common.

Thankfully, people are fairly predictable, especially in large numbers. RTOs and ISOs look at broad statistics – population, industry, and expected growth – and apply various predictive models to the known facts[10].

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[9] Clements, A. (2016, December 15). Small Power, Big Grid: Part 2. Retrieved October 18, 2017, from https://www.nrdc.org/experts/allison-clements/small-power-big-grid-part-2

[10] "Using Regression Analysis to Predict the Future Energy Consumption of a Supermarket in the UK." *Applied Energy*, Elsevier, 13 June 2014, www.sciencedirect.com/science/article/pii/S0306261914005674

And yet, the system remains delicate. Given how many organizations and companies are already enmeshed in the grid, one wonders how many more energy providers the system can handle. Can we support our local rooftop solar farms? What about small-scale/consumer-driven energy solutions like electric cars?

It comes down to a problem of coordination and storage – or lack thereof. Some extra energy wouldn't be a problem if there were a way to smoothly incorporate it into the system. But as it stands, our delicate system can be overwhelmed by extra energy. We don't have batteries or offline power plants that can keep reserves of electricity on hand.

Problems and Possibilities

Puerto Rico's grid used to work just like ours. When Hurricane Maria hit, 80% of the grid was wiped out, demonstrating another weakness of a unified grid system: if one part goes down, it all goes down.

Moreover, Puerto Rico has no fossil fuel reserves or refineries, which means that all its raw power material – coal, gas and oil – had to be supplied by freighter[11]. As of 2014, Puerto Rico was paying $100/barrel for petroleum[12], and Puerto Ricans spent almost four times as much on electricity as the average U.S. citizen despite using significantly less[13]. It seems illogical for Puerto Rico's electricity to rely on imported fossil fuels when it could instead harness the power of the sun.

For the sun to be a feasible source of continuous and reliable power, we need the capacity to store large reserves of energy. This would not have been possible ten years ago: batteries were prohibitively large and unreliable. Thanks in part to recent innovations in battery technology, as of earlier this year, the island of Ta'u can run exclusively off of solar power[14]. Its population ranges seasonally from 200 to 600, and its solar equipment – which takes up seven acres of land and includes over 5,000 solar panels and 60 Tesla Powerpack batteries – stores enough power for

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[11] Hruska, Joel. "Elon Musk Offers to Help Puerto Rico Rebuild With Solar Power."*ExtremeTech*, 9 Oct. 2017, www.extremetech.com/extreme/257148-elon-musk-offers-to-help-puerto-rico-rebuild-its-electrical-grid-using-solar-power

[12] Gross, D. (2014, May 30). Why Is Puerto Rico Burning Oil to Generate Electricity? Retrieved November 27, 2017, from http://www.slate.com/articles/business/the_juice/2014/05/puerto_rico_is_burning_oil_to_generate_electricity_it_s_completely_insane.html

[13] Morales, E. (2015, July 12). Puerto Rico's soaring cost of living, from giant electric bills to $5 cornflakes. Retrieved October 23, 2017, from https://www.theguardian.com/world/2015/jul/12/puerto-rico-cost-of-living

[14] How a Pacific Island Changed From Diesel to 100% Solar Power. (2017, September 15). Retrieved October 23, 2017, from https://news.nationalgeographic.com/2017/02/tau-american-samoa-solar-power-microgrid-tesla-solarcity/

three days with no sunlight. Establishing a similar setup in Puerto Rico, with its population approaching 3.5 million, is a task greater by orders of magnitude[15].

The ideal power grid has two key features:

1. The ability to incorporate varied sources of energy.
2. Microgrids that can continue operating even if a neighbor goes down.

Both these features contribute to the resiliency of the power grid. Incorporating various sources of energy not only enables more potential providers, but also prevents reliance on one type of fuel. If you can take advantage of wind when it's windy and sun when it's sunny, you've got hedges not only against the market, but also against the whims of nature.

The Resilience of Microgrids

Microgrids are independent power grids that can connect to a main grid. New York University has one cogeneration facility that withstood Hurricane Sandy[16]; when the rest of New York was without power, NYU was able to disconnect from the main grid and continue powering its hospitals and labs. It stands to reason that if Puerto Rico had microgrids, one broken link could not wipe out all the island's power. The effects of a failure at any one point could be contained.

But microgrids are currently limited to niche applications such as universities that require greater reliability than power companies can guarantee. In fact, certain states – and Puerto Rico – tax residents who go off-grid (e.g. those who power their homes through a personal solar setup). "It's the most perverse incentive system," says Hector Cordero-Guzman, a professor at Baruch College[17]. The logic, from the perspective of certain state governments, is that an off-grid tax offsets financial losses that would otherwise be passed on to loyal grid consumers. Because electricity is a public utility, the government can interfere in this way to protect the public from rising prices. Sadly, this policy benefits some members of the public at the cost of others, and disincentivizes self-reliance – and by extension, larger-scale resilience.

Given the complexity of the power grid, there are legitimate reasons that certain states might be unwilling to humor small-scale power providers. Coordination between the FERC, state-level

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[15] QuickFacts. (n.d.). Retrieved October 23, 2017, from https://www.census.gov/quickfacts/PR
[16] New York University. (n.d.). Retrieved October 23, 2017, from https://building-microgrid.lbl.gov/new-york-university
[17] Rao, A., & Melendez, B. M. (2017, October 16). How to Remake Puerto Rico's Grid to Survive the Next Storm. Retrieved October 18, 2017, from https://motherboard.vice.com/en_us/article/59d795/how-to-remake-puerto-ricos-power-grid-to-survive-next-storm-hurricane-maria

distributors and local power providers is already difficult; an increase in the number of power providers would improve resiliency at the cost of increased coordination.

Up until fairly recently, it made sense to link all power providers together due to their relatively limited number in any given geographical area. It used to be prohibitively expensive to get a power plant up and running; to this day, many incumbent power producers are still amortizing their costs from earlier construction of plants. But now small-scale power-producing infrastructure can be built up cheaply. And the more power-producing hubs and microgrids there are, the less any given failure will affect the larger system.

The question of how we move from centralized power grids to networks of hubs and microgrids remains open. The desperate situation in Puerto Rico may inspire a more resilient and diverse grid system that takes advantage of their natural (and renewable!) resources. If that happens, the continental U.S. may see the benefits of incorporating new grid technologies and rethinking related tax policies. We can only hope that it doesn't take a large-scale crisis in the lower 48 states to motivate a migration to a stronger and more diverse grid.