The Web of the Grid

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Luke Anderson

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

Advisor:

S. Travis Elliott, Department of Engineering and Society

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INTRODUCTION

Most engineers are oblivious to the fact that the "world's largest machine," what we call the grid, is dying (Bakke, 2016). The gravity of the demise of the electric grid is best explained within the socio-technical framework of technological momentum. As a case study, the fatal blackouts in Texas last February due to winter storm Uri is only one example of the growing problem of America's reliance on a fragile, aging grid. Across the United States, the frequency of blackouts has increased by more than 60% since 2015 (Flavelle, 2021). To explain why the grid is failing, we need to look at the history of America's dependence on public power.

STS CASE STUDY

On February 12, 2021, Texas Governor Greg Abbott declared a state of emergency due to the severity of winter storm Uri. The storm, caused by what climatologists call a polar vortex, forced the Electric Reliability Council of Texas (ERCOT) to shed load, which means cutting power to portions of the state, causing millions of Texans to lose power. On February 15, 2021, the frequency of the grid fell below 59.4 Hz, a safety threshold for electric appliances, for over 4 minutes, requiring further load to be cut. In total, over a hundred people died from the blackouts. It is important to note that Uri negatively affected all types of generators. Wind turbines, solar panels, coal piles, and pipes carrying fluids of all kinds froze over and quit working. Mistakes while executing the rolling blackouts caused critical generator failures, and several companies have since filed for bankruptcy.

TECHNOLOGICAL MOMENTUM

Thomas Hughes' socio-technical theory of technological momentum is that "as [technological systems] grow larger and more complex, [they] tend to be more shaping of society and less shaped by it" (Hughes, 1994). Simply put, when a technology spreads, its influence on the way people behave grows.

As public electric grids were adopted, they gained influence over people's lives and how new products are designed. Computers, for example, use low-voltage direct current, but the grid uses high-voltage alternating current, thus, adaptors are used to ensure compatibility between new devices and the grid. Clearly, the grid has played a major role in shaping innovation. As an ever-present source of public power, the grid influences every aspect of modern life. If "even a short regional blackout" were to happen, food would spoil, traffic would stop, and credit cards would stop working (Litos, 2022).

HISTORY OF THE GRID

The first electric grids were small, isolated strings of blindingly bright arc lamps suited for large warehouses and public areas. In 1879, the first light bulb suitable for indoor use was invented by Thomas Edison, and, in 1882, Edison created the first incandescent grid on Pearl Street in Manhattan. By 1884, it "held more than eight thousand bulbs … wired in parallel" (Bakke, 2016). To make money, Edison sold private replicas of his Pearl Street grid to wealthy individuals, and, as a rule of thumb, only used direct current. However, "by 1894, 80 percent of the grids being ordered and installed in the United States" used alternating current, whose voltage could be changed directly using a transformer.

The father of the grid, however, was Samuel Insull, the first to popularize the idea of communal, public power. A former employee of Edison's, Insull left New York to become the president of Chicago Edison in 1892, where he succeeded in creating a regulated monopoly by striking deals with government officials and factory owners. "He imagined electric light and power as products for the masses not the few [and] made it seem natural that the electricity business could only work as a monopoly" (Bakke, 2016).

THE GREAT DEPRESSION

The arrival of the Great Depression ended Insull's reign in Chicago, but his tactics had already caught on in other cities. "By 1930, nearly 90% of city dwellers had some access to electricity, but only one in 10 farmers in rural areas did" (Thompson, 2016). To expand access to quality electricity, President Franklin D. Roosevelt created the Rural Electrification Administration in 1935. In 1936, Congress passed the Rural Electrification Act, which "provided low-interest loans to farm cooperatives for the construction and operation of power plants and power lines in rural areas" (Merriam-Webster, 2022). Electricity use blossomed into the late 1970s, when, in response to the oil embargoes, President Jimmy Carter asked Americans to do the unthinkable of limiting their consumption. "In a deeper and more abiding way conservation became a part of how Americans thought about, used, and managed energy" (Bakke, 2016). In 1978, Congress passed the National Energy Act, which summarized these national sentiments by establishing mandatory efficiency standards for buildings and promoted renewable generation. The Public Utility Regulatory Policies Act (PURPA), which also came out in 1978, "required electric utilities to buy power from independent generators [which opened] the door for intermittent generation from renewable sources to enter—and even destabilize—the growing grid" (IER, 2022). After a century of controlling how and when electricity was produced, utility companies were now forced to purchase electricity from generative capacity they could not control.

PROBLEM DEFINITION

What PURPA did was force the utilities to purchase intermittent electricity at market value by allowing competition in the business of electricity production. The Energy Policy Act of 2005 ensured PURPA's success in adding variable generation to the grid by providing loans to organizations harnessing renewable energy. Meanwhile, utility companies are forced to bear the cost of taking this electricity to market. Without adequate grid-scale storage, if the utility fails to find a buyer, the electricity is wasted.

In Hawaii, for example, "one out of every eight homes … is equipped with solar panels, producing more electricity than the state needs on sunny days" (Bakke, 2016). In other states, like

California, “utilities pay wind farms to shut their turbines down on blustery days because the grid can't handle the power surge” (Bakke, 2016).

In 2014, “the [Environmental Protection Agency] proposed a new rule … to limit carbon dioxide emissions from existing power plants. The rule threatens to close a large portion of the reliable coal-fired electricity supply in the U.S. [and] will undercut power companies’ ability to meet electricity demand safely and reliably” (IER, 2022). “The EPA rule also comes at huge cost to American families and businesses that use electricity every day—by 2030, the rule is estimated to increase electricity bills by a combined $290 billion” (IER, 2022). With their hands tied behind their back by these kinds of regulations, utilities are forced to raise prices on consumers and cut costs by postponing critical maintenance. In short, “nearly every aspect of electricity is now heavily regulated by multiple federal agencies” (IER, 2022). “America's for-profit utility companies are fighting for their continued survival; a number of them … are actively dying” (Bakke, 2016).

GREEN ENERGY

The problem with green sources of energy, like wind and solar, is intermittency. Without effective storage, the grid is poorly equipped to balance normal demand with variable generation. All attempts to ignore this statement of fact have simply resulted in a higher number of blackouts. “From the 1950s to the ‘80s, significant power outages averaged fewer than five per year. But that’s changed. In 2007, there were 76, in 2011, more than 300” (Davies, 2016). Without grid-scale storage, the power that goes into the grid must instantly (at close to the speed of light) be used. When demand goes up, backup generators must respond within seconds or people lose power. Due to the technological momentum of public electricity, society has been conditioned to depend upon an ever-present supply of power, making blackouts dangerous. The state of the grid has led to a general feeling of dissatisfaction, and many are leaving it altogether (going off-grid). People have woken up to the harsh reality of an unreliable grid, costing them time, money, and freedom. Unfortunately, a mass-exodus away from the grid is making the problem worse for the utilities. Who are they going to charge for maintaining the wires, and who are they going to sell the electricity they were forced to buy under PURPA to? People are fed up with the lack of reliability and soaring electricity bills, and leaving accentuates the problem, making things worse for those who decide to stay.

WEATHER

The extreme cold was the main culprit for ERCOT's failure in Texas last winter. A precipitous drop in generation from natural gas, coal, wind, nuclear, and solar sources was caused by the freezing of critical components. At the same time, demand skyrocketed as everyone blasted their heaters. Such cold weather was indeed rare but not completely new to Texas. However, extreme weather events, such as snowstorms, heat waves, hurricanes, wildfires, and tornadoes are getting worse. In 2013, the White House stressed the importance of grid resilience as "climate change increases the frequency and intensity of severe weather," promising "more severe hurricanes, winter storms, heat waves, floods, and other extreme weather events … induced by anthropogenic emissions of greenhouse gasses" (Bakke, 2016).

CURRENT APPROACH

On June 8, 2021, Texas Governor Greg Abbott enacted legislation requiring power generation facilities, natural gas facilities, and transmission facilities to be capable of handling extreme weather. Hardening the existing grid is a common response to a lack of reliability, but it only accentuates the problem. Climate change will continue to push the hardened version to its limits. In Texas, for example, the cold weather in December 1989 and February 2011 had the same effects of a spike in demand and the loss of generating capacity as Uri in February 2021. In 1989 and 2011, the government tried to ensure readiness for extreme weather events in the future but ended up ignoring the root causes of the failures.

SMART GRIDS

Automating demand using computer algorithms "represents a significant investment but would yield numerous benefits" (NAS, 2022). In the 1970s, consumers proved they were willing to adapt to changing electric needs if given the choice. Today, smart meters represent a huge opportunity for utility companies to incentivize participation in remote automation programs, which means lowering electricity use to avoid a complete blackout. In Boulder, CO, the local utility, Xcel, tried to start a program like this but failed due to a lack of incentives and what residents believed to be a lack of empathy for the consumer. What they wanted was the freedom to set their own preferences within the program. They wanted discounts on the price of electricity for participating and unrestricted access to their own usage data. Smart grids also present cyber security risks as computers are used to "alleviate the abiding problem of peak load" (Bakke, 2016). However, consumers are understandably skeptical of electric utilities' ability to "remotely control electricity use" without causing problems (Bakke, 2016).

STORAGE

"As improbable as it may seem, though we have been making and using electricity for nearly 150 years, there is still no way to put it aside for later use" (Bakke, 2016). Since 1799, when Alessandro Volta built the first battery, the development of battery technology has progressed slowly, but electric vehicles represent a viable option for storing energy from intermittent sources if they can be seamlessly integrated into the grid at all hours of the day. "With car batteries backing up the grid, we could have more green power, fewer polluting backup power plants, and no robocalls asking us to switch off the AC on the summer's hottest days" (Bakke, 2016). Electric vehicles, if charged at night, could provide a nighttime load (use of power) that could be "discharged during daytime hours when these same vehicles are sitting in parking lots" (Bakke, 2016). Every parking lot in America could come with grid plug-in stations paying users for providing their stationary vehicles as storage vessels for the grid.

Green hydrogen, produced by splitting water, is also a viable way to store energy. Excess electricity is used to split water into its component gasses, storing the hydrogen until it is needed. The hydrogen is then pumped through a fuel cell, recombining with oxygen to form water, generating electricity in the process. Other storage options include pumped hydro, which is only viable in hilly regions, and compressed air, which can be stored just like the hydrogen. The reemergence of an old technology, the ice box, is also a promising solution to the problem of variable generation. Ice is easily formed using electricity during periods of abundant supply and allowed to cool a building when demand for electricity is high.

EFFICIENCY

Ground-source heat pumps (GSHPs) are a great way to save on heating and cooling costs by pumping heat into and out of the earth. Insulation can also have a big impact. In Djibouti, the Army's Camp Lemonier reduced its electric consumption by 40 percent simply by covering its tents with a layer of foam insulation (Bakke, 2016). Co-generation plants (central power stations that reuse excess heat), which promise super-efficient generation, are another promising innovation to alleviate the crisis of the grid. The U.S. Department of Energy's current goal for co-generation capacity is "20 percent … by 2030" (Bakke, 2016).

Despite tendencies on behalf of eco-friendly consumers to "go it alone" and avoid grids altogether, central power is and always has been more efficient. "Sharing, when it comes to electricity, is simpler and more cost-effective, than doing it for oneself" (Bakke, 2016). It also ensures equal access to the same quality of electricity among the populace.

REDUNDANCY

Overlapping grids with various types of generators, storage mechanisms, and distribution methods would be a game-changer in the race to ensure the resiliency and reliability of public electricity. The U.S. military and Google, entities with very little tolerance for power outages, are in the process of building microgrids at all bases and data centers. Even towns in Connecticut and New York are constructing redundant microgrids whose coverage overlaps with the existing coverage of the grid, with the latter "in the process of constructing eighty-three new microgrids" (Bakke, 2016). Microgrids allow us to slowly chip away at the technological momentum of the larger grid and move toward safer, less polluting plants while still promising "high-quality electricity to everyone" (Bakke, 2016).

CONCLUSION

Over-reliance upon an aging, central electric grid is a problem endemic to industrialized nations and stems from technological momentum, the idea that as any technology grows, it creates a system of societal dependency in its wake. America's dependency has reached the point at which access to reliable electricity is necessary to support our way of life. When the machine stops working, like it did in Texas last winter, people die. While politicians champion hardening the grid as the quick and easy solution, the construction of redundant, overlapping grids with independent supply chains is a surer step along the path toward energy security and offer multi-layered protection against blackouts. In these newer, more adaptable grids, solar panels, electric vehicles, and smart devices work in concert together to store intermittent power and release it to informed citizens.

"The hope now is that the power outages in Texas will provide important lessons and help avoid similar problems in the future" (Irfan, 2021). The fact that one grid, ERCOT's grid, was responsible for practically the whole of Texas should have raised people's eyebrows. It did not, though, because the American public has been conditioned, through the grid's influence on societal norms, to accept a monopoly as the natural way to provide public power.

The grid is fraying, yet we still rely on it. After every storm, we seem to lick our wounds by jumping for short-term solutions. In a recent report card, “the American Society of Civil Engineers gave the U.S. energy infrastructure a D-plus,” stating that “without greater attention to aging equipment, capacity bottlenecks and increased demand, as well as increasing storm and climate impacts, Americans will likely experience longer and more frequent power interruptions” (Martin, 2021). The electrical infrastructure of the future will most likely involve the regular hardening of parallel, independent micro-grids of various sizes with sufficiently different generation sources and storage solutions to protect cities against any type of natural disaster. In addition to extreme weather, the grid of the future will surely face cyber warfare, sabotage, and even direct attack. Electricity has become a basic element of our nation’s general welfare, and to maintain it, we should plan for the challenges of the future while learning from the hardships of the past.

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