Strengthening the Grid's Edge Using Diversity

By John Benson

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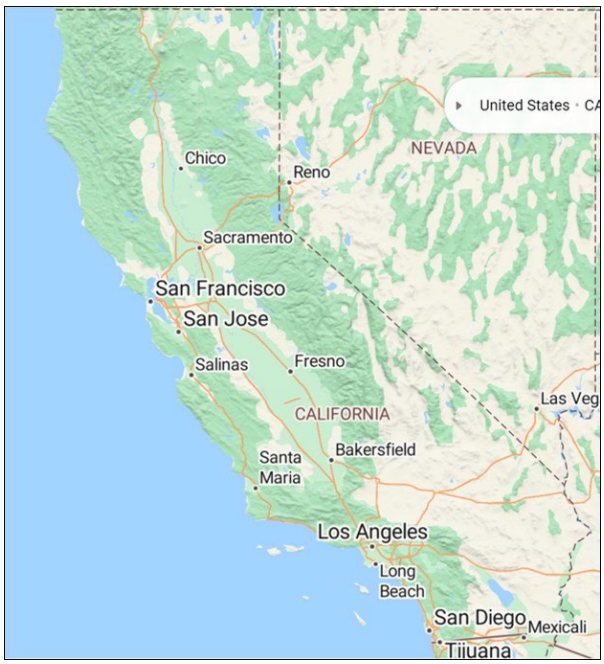
1. Introduction

OK, I get it. Most of the US is one big grid. There are natural boundaries (large lakes, mountain ranges, large national or state parks, etc.) that interrupt the US grid, but only states that have these features, or are the most sparsely populated have "grid edges." I live in the former, and somewhat in the latter for my home state, California.

Isn't California the most populous state? Yes, at almost 40 million people, but it's also a very large state (Texas and Alaska are larger). Also, the population is concentrated in 4 very high-density metro areas (by population: Greater Los Angeles: 18.6 million, San Francisco Bay Area: 7.7 million, Sacramento Metro Area: 2.68 million, and San Diego Metro Area: 1.39 million), and 10 to 15 cities that range from just over 500,000 to over 150,000. The above 10 to 15 cities are mostly in the Central Vally or the Inland Empire (north and east of greater LA). You will note that none of the above heavily populated areas are north of The Sacramento Metro Area nor East of the Central Valley. That leaves many areas with little or any grid, and plenty of grid-edges (see image below).



My wife and I have two homes. Our main residence is in Livermore (in the SF Bay Area), but my favorite place is our cabin in Arnold, California near a grid edge. The primary grid is parallel to the main Highway (Hwy 4). A few miles off of this, you will be in Stanislaus National Forest, and at or beyond the grid's edge. Residents that live near the grid edge frequently only have a single intertie to the rest of the grid, and lots of nearby pines and cedars to disconnect it via a large limb or tree-fall in the next major storm.

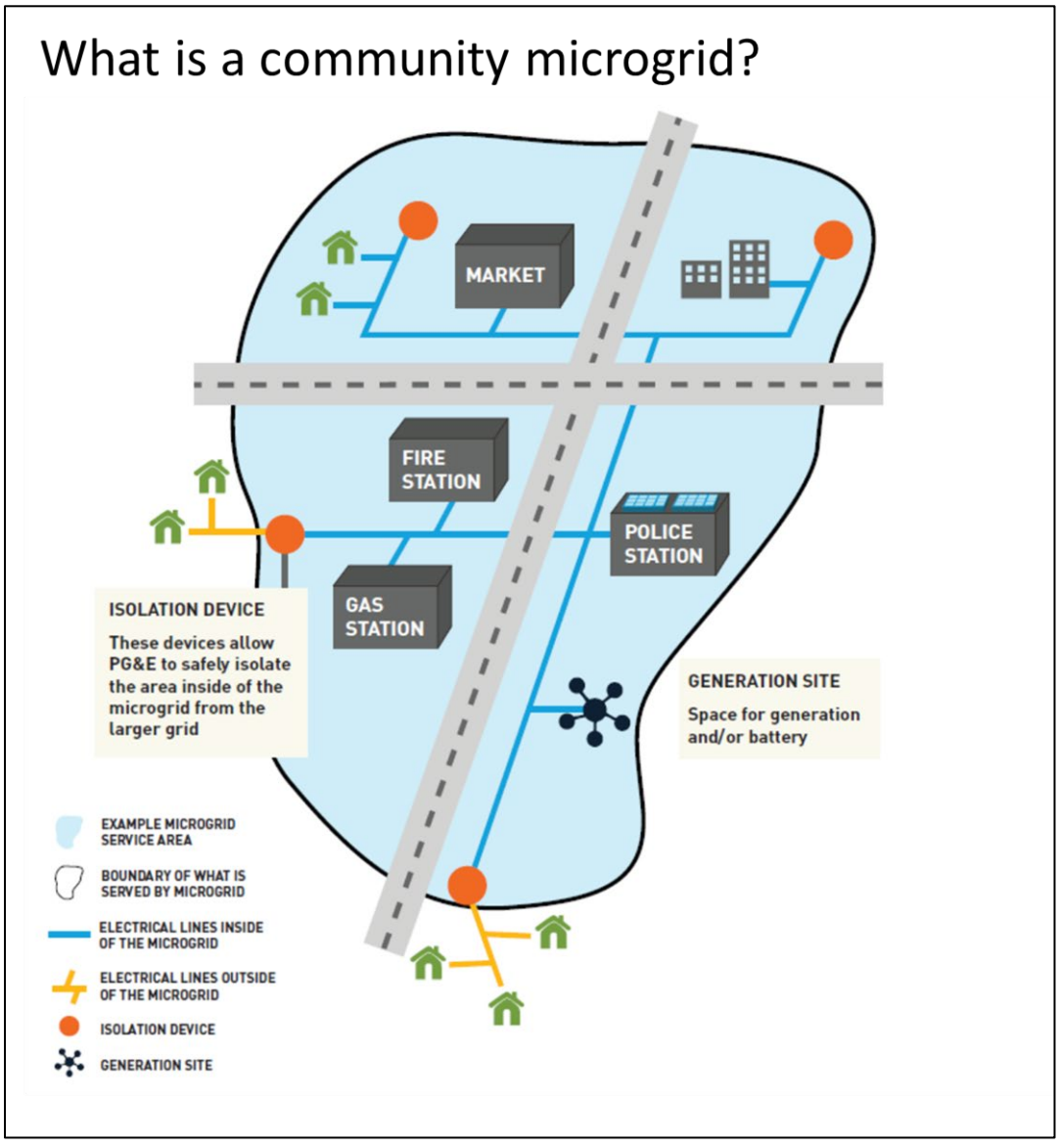
Yes, power is not reliable in this area.

2. Microgrids, Nanogrids, Outage-Proofing

My local electric utility is PG&E (both Livermore and Arnold), and they are currently undergrounding their main transmission and sub-transmission lines in remote areas, but this is simply too expensive to be widely deployed near all grid-edges. Their customers are already carping about rate increases to pay for undergrounding and similar grid-strengthening initiatives. Also, there are simpler and less-expensive approaches.

2.1. Microgrids

I work with microgrids and know that this is one approach to provide greater availability. A microgrid allows a given cluster of residences and/or businesses with a relatively secure distribution grid to add some source of generation and/or storage and form an island if the main connection to the greater grid is lost. PG&E is starting to enable Microgrids as described above, including in Arnold. This appears to have evolved into PG&E's Community Microgrid Enablement Program. See the figure and Link below.



https://www.pge.com/en/save-energy-and-money/rebates-and-incentives/community-microgrids.html

The generation is typically PV plus an emergency generator for times or situations when the PV is not adequate. The goal of the microgrid is to provide better power-availability in areas where the primary grid connection is periodically lost. Also note that microgrids also include a battery energy storage system (BESS) and microgrid control system to respond to short-term load changes and regulate frequency when operating as an island.

2.2. Nanogrids

Nanogrids are typically smaller versions of microgrids. They might be for a single facility, but will still have basic elements described in the prior subsection, with some simplifications. For instance, the basic configuration might be PV plus a BESS, and these might be mitigated by either load reduction in the facility and/or a portable generator that the Nanogrid can be plugged into to keep everything powered during the rare occasions when the BESS is running out of capacity.

2.3. Outage-Proofing

This is the option I have chosen. I'm in my Arnold home less than 20% of the time. I go up there to get away from it all, read, write, listen to my favorite music, and generally restore my sanity. I have lots of battery powered lighting and other appliances, plus kerosine lamps. Thus, I can do without electricity for a few days. Although I have central heat and (rarely used) air conditioning, I normally heat when I'm up there in winter via firewood, which goes into a big iron stove (which can also be used for cooking in a pinch).. I do not have an electric generator up there, nor do I need one. One other point: my wife and I have owned this house for about 25 years.

3. Mini-Grids

Arnold has a full-time population of around 4,000, but with lots of part-timers like me, it seems to more resemble (from the number residences and small businesses supported), a town with a population of over 5,000. I would estimate that my neighborhood (Meadowmont) has 200 to 400 homes that range from small (2 bedrooms, and one bath) the quite large (5 bedrooms and 3 baths). It also has a pretty large strip mall (Meadowmont Shopping Center) adjacent to Hwy 4. All of the above is fed by a small PG&E distribution substation near Highway 4.

If PG&E decided to power Arnold's neighborhoods during outages of the main electric intertie (which I would guess runs parallel to Hwy 4), the simplest method would be a back-up generator in or near the Arnold substation and batteries for regulation plus to conserve fuel. A diesel back-up generator would be a non-starter in California. Ideally, the back-up generation should be fueled with green hydrogen, but in the short-term it might be fueled with propane because the delivery infrastructure is in place in Arnold, and propane is a relatively clean fuel. PG&E might look for generators that could quickly be used with propane, but then later be modified to use hydrogen fuel. Most residences in Arnold currently use propane for heat and other uses. See section 5.2 below.

In lieu of, or in addition to emergency generation, one or more commercial-scale PV arrays could be added. This would reduce fuel-costs (for the back-up generation) and possibly reduce the size of the emergency generator and/or BESS.

3.1. A Real-World Example

Energy Vault is constructing a green hydrogen long-duration energy storage project, "the Calistoga Resiliency Center", in Calistoga, California.

Construction of the Battery/Hydrogen Energy Storage System (BH-ESS), which is being developed for Pacific Gas and Electric Company (PG&E) on less than one acre of land in the Northern California City of Calistoga, is expected to be completed by the end of Q2 2024. Upon completion, the BH-ESS, dubbed the Calistoga Resiliency Center, will be the first-of-its-kind and the largest utility-scale green hydrogen energy storage project in the United States. The battery portion of the system will be used to support grid forming and black start capabilities. The system will be prepared to power downtown Calistoga and the surrounding area for up to 48 hours during potential Public Safety Power Shutoffs (PSPS), which occur when the powerlines serving the surrounding area must be turned off for safety due to high wildfire risk. PG&E's proposal for the system was approved by the California Public Utilities Commission (CPUP) in April 2023.[1]

Energy Vault's BH-ESS will replace the traditional mobile diesel generators currently used to energize PG&E's Calistoga microgrid during PSPS events in the area. The project represents a major advance in community-scale microgrid development and a significant step toward realizing the CPUC's vision of cleaner forms of microgrid generation. "The timely start of construction is an important milestone in our partnership with PG&E to deliver this first of its kind microgrid solution. We greatly look forward to not only its delivery but most importantly to the sustainability benefits it will bring to the Calistoga community," said Marco Terruzzin, Chief Commercial and Product Officer, Energy Vault. "Our partnership with California's largest public utility is yet another example of the growing recognition that optimizing grid resiliency and economics toward achieving decarbonization goals requires innovation that leverages multiple technologies and a 'fit-for-purpose' customer-centric approach when designing energy storage solutions. The City of Calistoga and PG&E have been excellent partners for Energy Vault, and we are excited to bring this innovative project online in the coming months.

4. Diversity

Many residents and businesses in grid-edge areas similar to Arnold have already implemented their own solutions to power-reliability issues, like nanogrids, emergency generation (often fueled by propane) or outage proofing. There is no reason that these facilities could be excluded from solutions like the Mini-Grid described above. In Arnold we already have a smart metering system where the meters communicate with an advanced metering infrastructure (AMI). I also have this in Livermore, and I believe that most or all of PG&E's service area have these. I also know that smart meters can be equipped with remotely triggered disconnects for excluded customers.

In solutions like the above Mini-Grid, individual facilities should be able to opt-out, in which case they would be disconnected when the Mini-Grid was operating in an island-mode. This might allow a reduced size of the emergency generation and BESS.

5. Alternatives

Each grid-edge application will very-much be a custom application. Each should also be designed and implemented by the incumbent utility. What I've tried to do with the above report is to use an area I am very familiar with to outline some solutions. In my earlier years in my cabin, I spent many hours hiking in the woods around Arnold.

[1] Energy Vault News Release, "Energy Vault Begins Construction of the Largest Green Hydrogen Long Duration Energy Storage System in the U.S." Feb 22, 2024, https://investors.energyvault.com/files/doc_news/Energy-Vault-Begins-Construction-of-the-Largest-Green-Hydrogen-Long-Duration-Energy-Storage-System-in-the-U.S-2024.pdf

I'm also am a cross-country skier, and thus drive almost up to the Hwy 4 winter-closure section to go skiing (at Bear Valley XC). Ebbetts Pass goes over the crest to the Eastern Sierras, and is over 8,700 ft high. That's a pass too high (with too little traffic) for Caltrans to try to keep open in the winter. Both my brother and mom lived in Carson City, NV, so earlier, I often made the full trip at other times of the year.

5.1. Wind Power

Every few years I look at medium-sized wind-turbines. Since I hike quite a bit in the Sierras, I know that ridge-top areas there have high winds, which could represent an opportunity to power infrastructure in these areas with windpower + storage. There is just one problem. I'm guessing the right capacity for these turbines is in the 20 kw to 100 kw (rated output) range. So, I looked at several recent sources that cover this technology and market, most notably the site linked below.

https://www.nrel.gov/news/program/2022/nrel-selects-manufacturers-of-small-and-medium-sized-wind-turbine-technology-for-2022-2023-funding.html

The problem is I only found one established and reasonably healthy manufacturer of this size wind turbines the US (linked below).

Bergey Windpower Co.

https://www.bergey.com/

It appears that the rapid rise of PV, along with its rapidly decreasing cost and its scalability has mostly displaced at least this range of medium wind turbines. This is why wind technology was not mentioned earlier.

5.2. Hydrogen-Fueled Combustion Turbines

In past posts I have covered the evolution of combustion turbines (CTs) to be able to use 100% hydrogen fuel. Both GE and Siemens are major participants in the industrial-range combustion-turbine market (and are each one of my former employers). Unfortunately, their CTs are much too large for our target application.

The good news is that there is a class of CTs, Microturbines, that start out around 50 kW, which would work for some applications. These also can be fueled with propane. Although the current state of the art for hydrogen-fueled microturbines is around 30% hydrogen. However, they can be fueled with 100% biomethane, which is also renewable. The other good news is that there is a leading microturbine manufacturer, Capstone Green Energy, in Van Nuys California (near LA). Capstone turbines can use biomethane fuel, and there is quite a bit of biomethane production in California's Central Valley.

The bad news is that there is no distribution infrastructure in place for distributing biomethane. It is possible to transport biomethane via liquefaction (like propane) and using insulated tanker trucks and storage tanks, or by compression and using high-pressure "tubes" and tube trucks or tube-storage. For more information see the reference below, pages 78 & 79.

https://suscon.org/pdfs/news/biomethane_report/Chapter_4.pdf