Managing the Duck Curve and all of Its Foul Relatives

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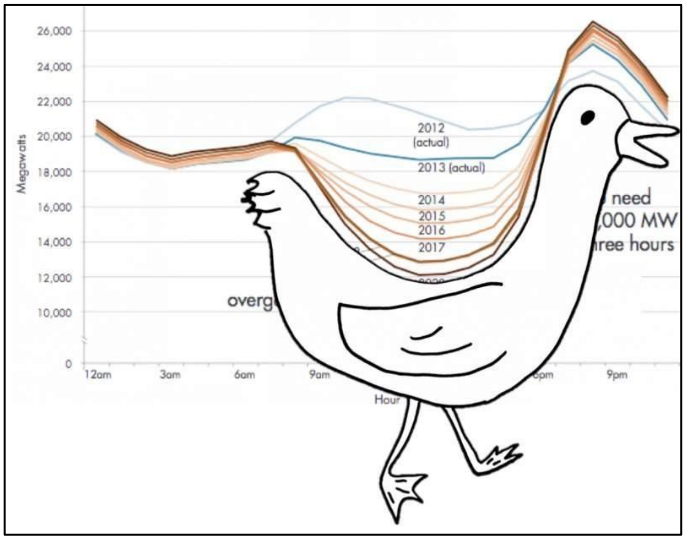
1. Introduction

Electric utilities have been fighting the mismatch between when power generation is available and when the loads need the resulting electricity since Edison, Tesla and Westinghouse invented the modern electric utility industry.



The "Duck Curve" is a somewhat new species for this issue, but I'm sure we will be seeing more of its flock-mates as the grid-supply evolves.

In 2013, the California Independent System Operator published a chart that is now commonplace in conversations about large-scale deployment of solar photovoltaic (PV) power. The duck curve—named after its resemblance to a duck—shows the difference in electricity demand and the amount of available solar energy throughout the day. When the sun is shining, solar floods the market and then drops off as electricity demand peaks in the evening. The duck curve is a snapshot of a 24-hour period in California during springtime—when this effect is most extreme because it's sunny but temperatures remain cool, so demand for electricity is low since people aren't using electricity for air conditioning or heating.[1]

High solar adoption creates a challenge for utilities to balance supply and demand on the grid. This is due to the increased need for electricity generators to quickly ramp up energy production when the sun sets and the contribution from PV falls. Another challenge with high solar adoption is the potential for PV to produce more energy than can be used at one time, called over-generation. This leads system operators to curtail PV generation, reducing its economic and environmental benefits. While curtailment does not have a major impact on the benefits of PV when it occurs occasionally throughout the year, it could have a potentially significant impact at greater PV penetration levels.

While the mainstream awareness of these challenges is relatively recent, the U.S. Department of Energy's Solar Energy Technologies Office (SETO) has been at the forefront of examining strategies for years. Most of the projects funded under SETO's

[1] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, "Confronting the Duck Curve: How to Address Over-Generation of Solar Energy", Oct 12, 2017 https://www.energy.gov/eere/articles/confronting-duck-curve-how-address-over-generation-solar-energy

systems integration subprogram are performing work to help grid operators manage the challenges of the duck curve.

The duck curve represents a transition point for solar energy. It was, perhaps, the first major acknowledgement by a system operator that solar energy is no longer a niche technology and that utilities need to plan for increasing amounts of solar energy. This is especially true for places that already have high solar adoption, such as California, where one day in March 2017, solar contributed nearly 40% of electricity generation in the state for the first time ever.

Last week's post (linked below) described all of the large photovoltaic projects in the U.S., and the number and size of these are growing rapidly. Clearly we need to be prepared to deal with over-generation and under-generation wherever they occur.

https://energycentral.com/c/cp/2021-photovoltaic-bess-projects

This paper will address mismatches between electric supply and demand. I will do this for my home-state (California) and others can do the same for their home state.

2. Solutions - Supply

Other that the description of the quackery above, instead of trying to identify all of the foul beasties in this particular menagerie, I will simply propose solutions that should work to shift supply and/or demand and thus the methods to mitigate these issues. This section will do this from the supply-side. The following section from the demand-side. The final section will cover solutions that work both sides of the curve.

2.1. Supplemental Generation

California has two types of generation that can pitch in when there is not enough electric energy supply. These are described along with their limitations in the subsections below.

2.1.1. Dispatchable Hydroelectric Power

All large hydroelectric power plants are heavily constrained. Most of these constraints have to do with the maximum and minimum amount of water they can flow through their hydro-electric turbines. Although I'm not going into details on this subject (lest this become a paper on hydroelectric engineering), the flow is constrained by environmental, recreational, economic, and water-supply issues. However, hydro plants do have some latitude in their daily time of dispatch for flow/generation, so they can reduce this in time of over-supply and store the water, and then use the stored water to increase generation in times of under-supply.

In California during a wet year, this full latitude is available for most of the year. However in an extreme drought year (like 2021), the maximum flow is greatly reduced for most hydro power plants, and thus the latitude. In late-summer to early-autumn in an extreme drought year, the latitude mostly goes away.

2.1.2. Gas-Fired Combined Cycle

At this point in time, most of the combustion-turbine "peakers" have been retired, or should be shortly, so I will skip these. There are a large number of combined cycle plants still operating, and they have a path to very low GHG (via biomethane in lieu of geologically-sourced methane, a.k.a. natural gas), and a further path to negative emissions technology. Thus the newer combined cycle plats may stay around for a while. See the 2019 post below for more information on the GHG reduction processes.

Zero-Emissions Combined Cycle and Beyond: *This paper has a proposal that will keep combined cycle power plants running by converting them to (nearly) zero greenhouse gas (GHG) emission operation. Ultimately these can be converted to negative emissions technology to offset other GHG sources.*

https://www.energycentral.com/c/cp/zero-emissions-combined-cycle-and-beyond

There are three reasons why combined cycle plants should be retained in the generation mix for some time: (1) they can be run at any time during the day or year, (2) they are moderately fast responding (both start-up and ramping), and (3) their potential to evolve to negative emissions technology, which will definitely be required in the future.

2.2. Generation Diversity

The best laid plans… You know the rest. One might hypothesize the perfect generator, but of course, it does not exist. All generation plants have a combination of attributes. Also, as climate change throws us pitches we have never seen before, the transmission and generation for each new situation may require a mixture we've never used before. And we need to craft these new mixtures such that they don't break the bank. Oh yes, and keep the lights and HVAC on (hello, ERCOT), and not destroy anything (hello, PG&E).

Diversity requires considering the following elements:

- Daily and yearly availability times
- Start-up and ramping speed
- The cost per kWh to build and operate a generation project while making a reasonable profit
- The amount of GHG emitted
- Specific issues for a specific large plant in a specific year, like a scheduled maintenance outage
- Other factors, like ability to provide ancillary services, other types of pollution, down-times, technology-risk, other environmental risk, the location of generation, and transmission capacity that allows them to move power to load centers.

When the California Independent System Operator (CAISO) plans short-term future operations it uses various models to forecast load throughout a future day and optimize the generation schedule needed to meet that load. In the event that something unexpected changes as the schedule is being executed (called a contingency, and this might be an equipment failure, inaccurate weather forecast and/or other events that could not be reasonably forecast) they make the most economic adjustments to the dispatch schedule.

The unexpected events are where the need for rapid response is critical. The generation that responds most rapidly is hydro and combined cycle. Also see the subsection on battery energy storage systems (BESS) below, as they can respond much more rapidly than any generator.

2.3. Distributed Energy Resources (DER)

DER are currently mostly part of the problem (contributing to the solar generation fall-off in late afternoon). However as these add storage, they can be incentivized to use that storage to kill the foul beastie.

For instance, for my primary residence I switched my PG&E Tariff to E-TOU-D in May. This is a time of use tariff that has a peak pricing period from 5:00 to 8:00 PM on weekdays.[2] I don't have photovoltaic (PV) on my roof yet, but if I decide to add this, it will definitely be with storage (like Tesla Powerwall). In the summer the peak pricing is about $0.10 a kWh higher than the normal pricing, so should I add PV, I will program the storage application to take over 100% of the house load during the peak period. Also the charging energy for my storage unit will come from the peak output of my PV, thus helping to moderate peak generation from other PV without storage. For more details on the PV+storage configuration, see the recent post described and linked below, Section 2.

The Future of Microgrids: *I responded to a question from one of my colleagues at Energy Central, which caused me to think about the subject of this post. This brought up some interesting possibilities.*

The California Electric Utility Culture has decided that microgrids will be very useful to prevent transmission lines that feed small isolated communities from starting wildfires.

This post will expand on the possibilities for microgrids to expand into other segments once the wildfire mitigation market starts to saturate.

https://energycentral.com/c/ec/future-microgrids

2.4. Curtailment

This is the worst-case scenario: if the transmission system cannot handle the peak output of PV projects and/or any other non-dispatchable renewable (read: wind power), these will need to be curtailed. This is why many large PV projects are adding large BESS as quickly as these can be delivered and installed. Also, getting paid extra for energy delivered during the peak demand period more than offsets the amortized cost for developing and supporting the BESS.

Wind-power is not as easily mitigated in California as its variability is both less predictable, and has a much longer period (read: several days with very little wind). Thus it cannot be effectively mitigated by short-term storage like PV.

3. Solutions – Demand

Demand-side management (DSM) has been around since 1938, albeit with the "load management" name. Until recently this was a simple method to cycle individual loads like air conditioner compressors in order to shave the peak demand.

[2] PG&E Tariff Page, Electric Rate Schedules, E-TOU-D, https://www.pge.com/tariffs/index.page

3.1. Modern DSM

Recently DSM has become more sophisticated via adaptive algorithms, and even autonomously responding to frequency sag caused by overloads. In an emergency these systems can be instructed to trip their loads (rather than cycling) for short periods.

Also note that the scenario described in subsection 2.3 could be considered a demand-side resource, specifically: “rate-driven switching to internal resources during peak-demand”. This has the same effect as tripping off an air conditioner compressor, except I would be virtually tripping off my whole house rather than just the AC compressor (and I would stay cool).

3.2. Automated Demand Response (ADR)

ADR is a technology and an organization to support this. The technology is developed using the Open ADR Specification, which is now in version 2.0. The organization is the Open ADR Alliance, and its site (and the specification) is through the link below.

https://www.openadr.org/

The open ADR specification describes a robust and expandable structure to be used for developing a system to control distributed demand response and distributed energy resources. The specification describes the creation, management and operation of this resource.

One type of resource that an open ADR system might manage is the charging of electric vehicles (EVs), and eventually manage EVs acting as vehicle to grid (V2G) distributed resources. This will probably also require an intermediary capable of building an OpenADR system, and establishing conditions and incentives under which EVs can operate in a V2G mode, while retaining sufficient charge to provide the required mobility.

3.3. Microgrids

Some microgrids are permanently disconnected from the grid, but most probably have a connection to a transmission or distribution line. One of the reasons for building a microgrid is an electric supply that is capable of riding through an outage. Along with this capability is the possibility of voluntarily disconnecting from the grid in an emergency. There would need to be a financial incentive for doing this. Many electric tariffs have interruptible provisions, so the incentive would probably be via one of these tariffs.

4. Solutions – Supply plus Demand

Supply plus demand, generally means storage. Ideally a Battery Energy Storage System (BESS), will charge when supply exceeds demand, and thus electricity pricing is really low (late morning to early afternoon for most of the year in California) and discharge when demand is at a peak and electricity pricing is really high. This provides a strong positive operating margin that helps amortize the cost of BESS development.

In today’s environment a BESS may be paired with a photovoltaic (PV) project and increase the efficiency of charging via a DC-coupled design: the output of the PV is DC as is the input/output of the batteries, however a DC/DC converter may be needed to match voltages.

A BESS can also provide Ancillary Services like Regulation, Spinning Reserve, Non-Spinning Reserve, and Voltage Support, and is particularly well-suited to provide Regulation Service as it can start or ramp in seconds to respond to an emergency.

For additional information on BESS see the earlier post below, sections 2.2 and 2.3.

Photovoltaic plus Storage: *This is a two-part series. Part 1 is on new technologies for utility-scale PV, utility-scale storage, PV plus storage systems, and the evolution of their missions.*

https://www.energycentral.com/c/cp/photovoltaic-plus-storage-%E2%80%93-part-1-technology

Also note that long-term storage available, and California already has this via pumped storage facilities. See section 4 in the earlier post below for more information on this.

Long-Term Storage: *This paper describes long-term storage technologies, some economic considerations, and recent developments.*

https://energycentral.com/c/cp/long-term-storage