the 2020 California Blackout: Another Electricity Crisis?

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At a time of remarkable acceleration in the worldwide economies' transition to clean energy, California state, which is comparable to the world's fifth-largest economy India, has been leading all states in the U.S. for consecutive years. The renewable market trends and clean technology advances started by California wields enormous power to influence environmental policy nationally and even globally. The progress of California's energy market transition thus is closely watched by public and media. Nearly 20 years ago, shortly after California turned to the new wholesale power market and innovative customer choice program, a series of significant supply shortages and blackouts in California had attracted much attention from the media. The arguments on market manipulation, aftermath of several utility bankruptcy, and temporal economic stagnation still haunted the California people until now. However, 20 years later, on August 14^{th}, 2020, grid operator California Independent System Operator (CAISO) again issued a series of short-term rolling blackouts. As many as 250,000 people were involved in this power off. For the first time since 2001, California is suffering another energy emergency and makes the headlines of major newspapers in the world again. But how exactly is this happening? Why weren't the power managers able to plan ahead for this? And most importantly, what's the essential difference between two outages in two decades? In this writeup, we will dive into some details of the darkening California electric system and find the culprits behind two supply shortage events.

The August Blackouts in California

On August 14^{th}, Friday, as a record-breaking heatwave gripping the Western U.S., California grid was pushed to its limit – enormous air conditioners were put into use, aggregated electricity demand has reached a peak level. At 2:56 p.m., a 475-MW natural gas generator

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loss first forced CAISO to declare a Stage 2 emergency*, forecasting hours of potential energy shortage. Then, as solar generation declined in the late afternoon, the unexpected out-of-service of another 750-MW backup generator further prohibited CAISO from quickly ramping up production and meeting contingency reserve obligation. To protect the grid's stability and avoid more serious outages induced by ballooning demands, CAISO then issued a Stage 3 electricity emergency order asking Utility Distribution Companies (UDCs) to order short-term rolling blackouts. Not known in advance, a total 1000 MW load shed was ordered consecutively in 10 minutes. Approx. 250,000 people were cut off, mostly in the service area of Pacific Gas and Electric (PG&E). The load was not restored until approx. one and a half hours later at 7:56 p.m. The next day, on August 15^{th}, a quick fall of 1000-MW wind generation combined with another 400-MW natural gas generator loss in the late afternoon brought ramping issues to CAISO again. With inadequate resources to dispatch, CAISO ordered another 470-MW of load shed from UDCs. Though still caused great inconvenience, this rolling blackout lasted less than one hour and was adequately alerted ahead. 22 minutes after the load shed order, CAISO received emergency assistance, managed to call additional resources, and successfully restored all loads.

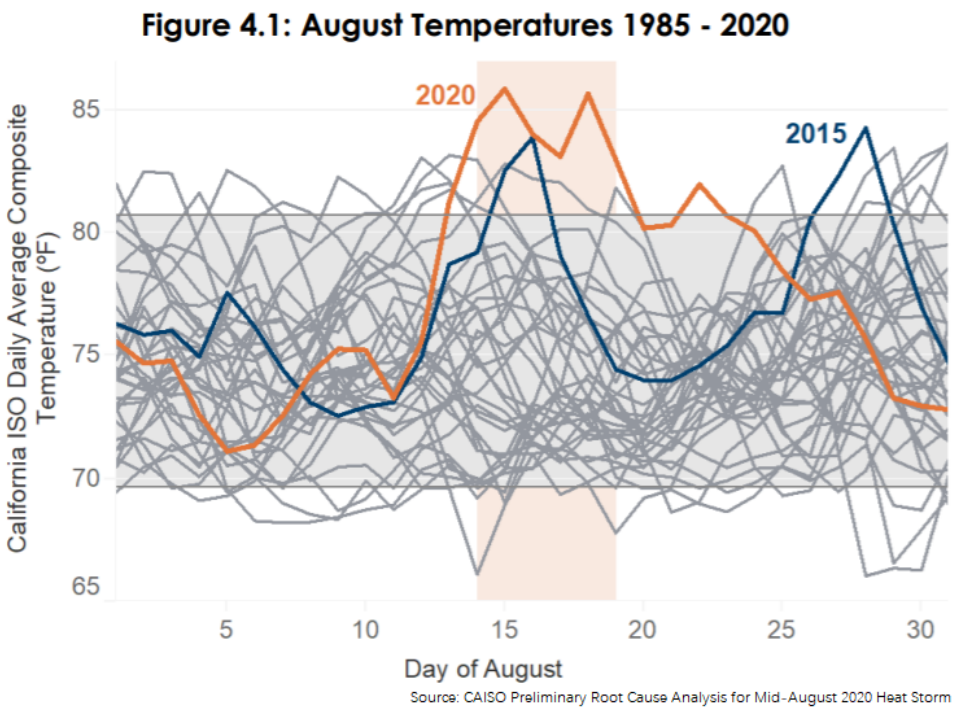

Figure 1: August Temperatures in California, 1985-2020

*According to CAISO, **Stage 1**: Strong need for conservation; **Stage 2**: Requires ISO intervention in the market, such as ordering power plants online; **Stage 3**: Notice issued to utilities of potential electricity interruptions

In these two days, with insufficient electricity available for meeting high consumer demand in specific time periods, electricity prices at the wholesale market also skyrocketed. Figure 2 shows the 24-hour locational marginal price (LMP) in day-ahead electric market at a node in the Los Angeles area from August 13^{th} to 15^{th}. As CAISO failed to bring online enough reserves to maintain system load, the scarcity pricing mechanism was triggered, which lead to hours of abnormal price in the energy market and ancillary service market. As seen in the figure, the electricity price per megawatt-hour can spike to over \$900 from 7:00 p.m. to 8:00 p.m., an extremely high value compared to a few tens of dollars at similar times on August 13^{th}.

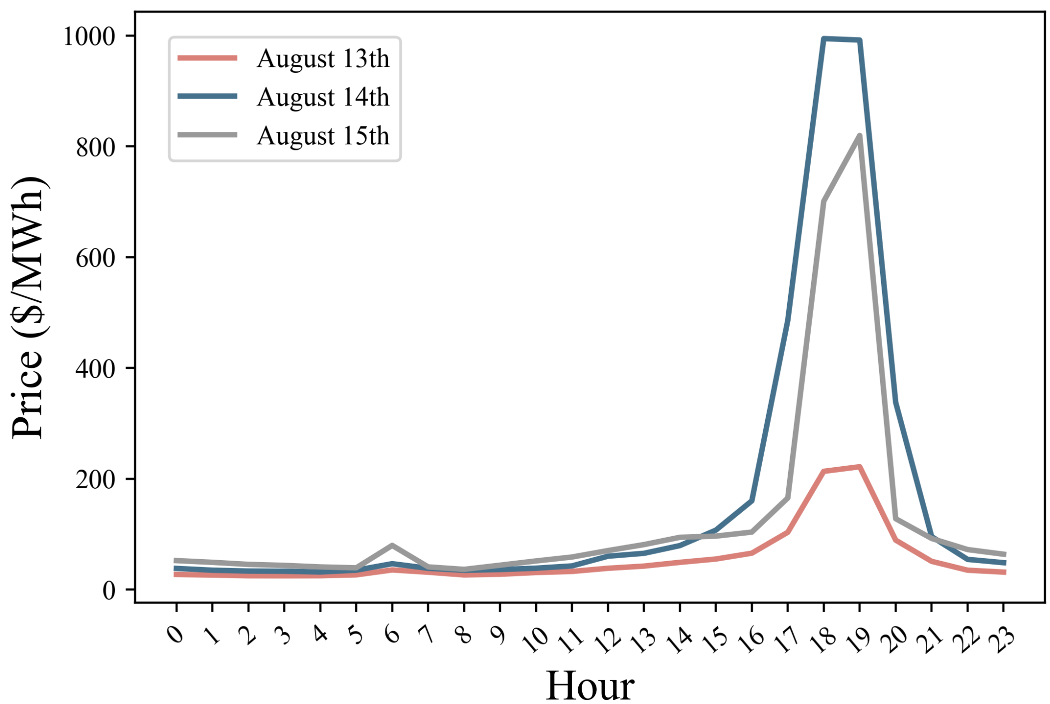

Figure 2: LMP at node *LCIENEGA_6_N001* in the Los Angeles area from August 13^{th} to 15^{th}

On the following Monday, cooler-than-expected weather temporarily released households from enduring another round of outages. However, customers were still asked to reduce electricity consumption from late afternoon to evening under a "Flex Alert", considering that excessive heat warnings still exist. Even Tesla was urging its EV owners in the California area through connected car screens to limit Supercharging or home charging between 16:00 p.m. and 21:00 p.m. for helping relieve grid stress. On August 17^{th} and 18^{th}, two Stage 2 electricity emergency orders were issued. The next emergency alert did not come until Sept. 5^{th}, when heat wave loomed again, loads began to trend up, as well as wildfires caused a total of 1600-MW generation loss. Fortunately, as the Stage 2 energy alerts and emergency appeals for conservation kicked in in the afternoon, residents and small businesses all well responded to drop interruptible loads and conserve energy use, which avoided any further emergencies and rolling outages.

So far, in August and September, CAISO issued 8 electricity emergency orders altogether, including two of Stage 3 and six of Stage 2. Under most urgent situations, residents were asked to be as conservative as possible, and suppliers were encouraged to provide additional and bid in the ancillary market. Now, as the heat season passed, people's concern about power outages also no longer exists.

Is this a series electricity crisis?

Admittedly, the power outage had brought much inconvenience to people's lives, especially during a time when the COVID-19 epidemic trapped people to work from home and increased their reliance on household electric appliances. Already, some have tried to politicize the blackouts and exaggerate the effect to be produced, blaming the ISO and state's improper ambition in renewable transition. Indeed, If CAISO should be blamed for this outage, they might have been responding slowly to the supply shortage on August 14^{th}. However, despite all the criticism and scaremongering from public media, generally speaking, CAISO has responded reasonably well to the situation – actual blackouts during the heatwave were relatively small (1470 MW) and of short duration, which makes this power shortage far from a serious energy crisis. This is especially true when compared to the northeast blackout of 1965 or 2003. The latter was a widespread power outage spanning from Northeastern and Midwestern U.S. to the Canadian provinces of Ontario on August 14^{th}, the same day in 2003. Over 50 million people in eight U.S. states and Canada were affected, total economic cost was estimated to be between $7 and $10 billion. Varying between locations, the duration of power outage ranges from 2 hours to a maximum of 4 days, makes it the world's second most widespread energy crisis in history.

Therefore, instead of depicting this time's California blackout as an "electricity crisis", the emergency alerts and CAISO's reasonable responds are more of preventative measures to ensure grid stability and avoid more serious system collapse. For one, an electric grid is not a perfect science, it is not designed to be foolproof. Ideal reliability is either hard to guarantee or extremely costly. Therefore, in the case of local obstacles, to keep broader interconnected grids in a relatively stable operation state, small-scale and short-term outages are acceptable for preventing the entire system from crashing and enabling the area in shamble to quickly resume normal operation. For another, the flex alerts are in fact the consequence of compromise between grid reliability and system carbon footprint: the imbalance between lost flexibility resources, e.g. coal power or natural gas, and thrived renewable energies with high intermittency will inevitably lead to some system inabilities which require customers to step in and respond. This will be explained in more detail later in the writeup, but the point here is that, politicizing the whole story and portraying it as an energy system crisis is both unreasonable and unwise.

Additionally, pre-emptive blackout is one way for utilities to prevent severe wildfires ignited by plants knocked on power lines. California had its most destructive wildfire season on record in 2018, with a total of over 7,500 fires burning an area of over 1,670,000 acres. The most devastating batch of fires, including the Woolsey Fire and the Camp Fire, killed at least 85 people and destroyed more than 18,000 structures, becoming California's deadliest wildfire in the state, and even the nation's wildfire history. Notably, it has been determined that one cause of the Camp fire was distribution lines managed by PG&E, California's largest utility company: power lines failure combined with warm and windy weather together contributed to the quick spread of the fire. Consequently, PG&E not only had to endure liabilities exceeding $30 billion in connection with fires but was also facing criminal charges including murder or involuntary manslaughter regarding the blaze. Being hit with a flood of lawsuits, PG&E filed for bankruptcy protection in late January 2019. Facing such a tough lesson, during the wildfire season in 2019, the three utility companies in California all included intentional blackouts as part of their strategies to prevent wildfires caused by electrical equipment. Though did not completely prevent the spreading of wildfires, these pre-emptive measures at least made wildfires in 2019 less destructive than those in 2018. Therefore, from August 14^{th} to 16^{th} in 2020, when utilities simultaneously faced a "red flag" warning for high fire threat along with the extreme heat and spiking electricity demands, it was no surprise that they may tend to shut down transmission lines and issue planned blackouts to constrain potential losses to a possible minimum, instead of taking risks struggling to bring online generation resources in the high-threat area.

Considering all, while the blackouts and flex alerts in August did expose some urgent challenges California electric system needs to deal with, it is not appropriate to describe the whole event as a "crisis". We then are interested to know, why on earth were that many media keeping close eyes on it and sometimes exaggerating its impacts? What worrisome have left on people's minds 20 years ago that makes them so concerned about the electricity shortage in California?

What happened in California 20 years ago?[†]

On January 17^{th}, 2001, as the lights literally went out in "one of the wealthiest and most technologically advanced regions on earth"– California, so matured the 2000-2001 California electricity crisis, also called the Western Power Crisis. Poor hydropower supplies due to drought conditions, inadequate power infrastructures, and a flawed power market design which leads to the market manipulation, together contributed to skyrocketing electricity price, multiple large-scale blackouts, utility companies collapse, and substantial economic loss in California.

[†]Most of the information and stories in this section are from the book *Market Power and Market Manipulation in Energy Markets: From the California Crisis to the Present* I am reading recently.

In the long run, this market failure casted a pall on spirited movements towards deregulation throughout the whole U.S. and left California state a tough but wealthy lesson on future electric power system restructuring.

Here is how the story started: In September 1996, California legislature embraced the California Public Utilities Commission (CPUC) restructuring framework under Assembly Bill 1890 (AB1890, the Electric Utility Industry Restructuring Act), which opens their retail markets to competition. As an early leader in this innovative exploration, California was unique in both its design and operation: California Power Exchange (PX) was formed to take responsibility for wholesale power procurement, while CAISO was set up to run transmission systems and ultimately maintain system reliability by balancing supply and demand in real-time (RT) electric markets. The IOUs would then procure most of their power needs in the PX day-ahead (DA) market and rely on CAISO Imbalance Energy market or Ancillary Services Markets in real-time to address incremental supply or demand fluctuations. In the first two years of operation (until December 1999), the two energy markets ran smoothly as a workably competitive market should deliver. However, signs of turmoil first showed in late April and early May 2000, when one zonal electricity price spiked strongly to reach the cap of \$750/MW in CAISO's RT market. This signaled the origin of the crisis: power supply shortages.

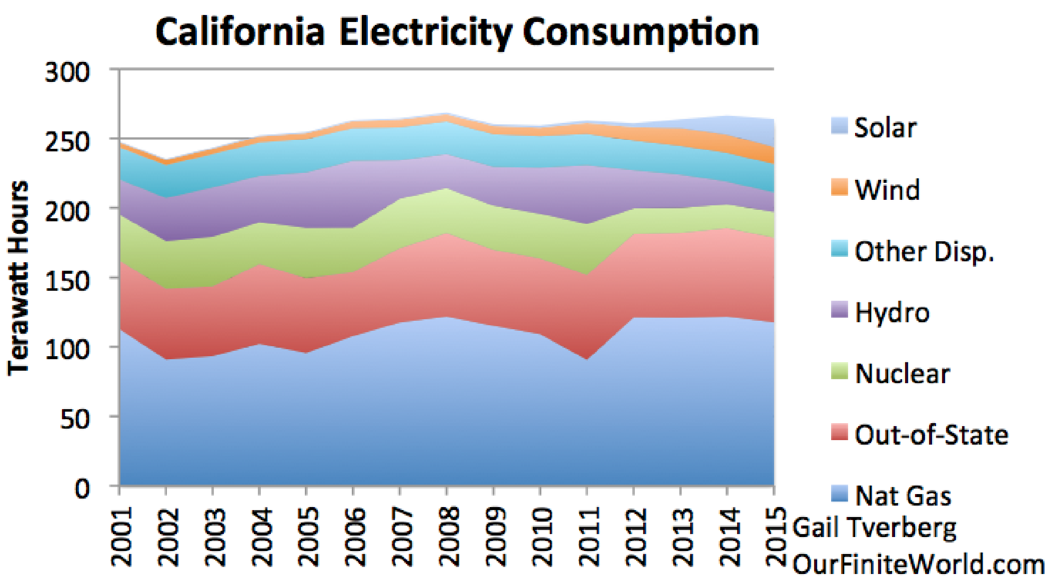

Figure 3: California electricity consumption mix

In the early 2000s, California relies heavily on out-of-state electricity imports to fulfill domestic consumption (contribute to one-third of total usage, see Figure 3). However, the particularly hot summer in 2000 made less surplus electricity available from neighboring states. In the meantime, the 2000 drought in the Pacific Northwest, whose hydroelectric dams were another source of supply for California, led to less hydropower available to be delivered. And even more, one important nature gas pipeline serving the state exploded in the summer of 2000 and its owner was not able to bring the pipeline back into service until months later. With a supply disruption, natural gas power plants in California also lost momentum. These imbalances between supply and demand all drove the soaring electricity price: after the first spike in May, similar price jumps happened repeatedly throughout the whole quarter. In June, the monthly average prices in the PX and CAISO rose to \$132.35/MWh and \$262.73/MWh, respectively, which were over 400% of the June 1999 levels. The PX DA market price even rocketed to \$1099/MWh during peak hours on June 28^{th}, 2000.

Though facing a huge run-up in wholesale electricity prices, IOUs in California were not able to recover these costs in the retail market, and they had no way but to absorb it. This is because, for one, no matter how much was spent on wholesale, the retail rate IOUs can charge from customers is capped by CPUC. For another, the original market design stipulated that over 80% of the electricity sold in California must be transacted through the PX market. Long-term electricity contracts between generators and IOUs were forbidden. This left utilities the only option to procure expensive electricity for fulfilling load obligation. Some sophisticated ways took advantage of by speculators made this situation even worse: since IOUs, by all means, would have to purchase, several trading companies, led by Enron, further drove up wholesale prices by deliberately declaring generation plants "out of service" and pulling them out of the market. They persuaded generation suppliers not to bid in the PX DA market, neither in CAISO's RT and Ancillary Services market. Consequently, as a supply shortage already existed, CAISO's grid operator had even fewer resources available for dispatching, so they have to accept preposterous prices provided by traders and pay sky-high surcharges to procure power. In this way, Enron traders reap enormous profits for the company by exploiting loopholes in California's flawed electricity market, but multiple financial problems began to emerge in the three utility companies.

After spending \$9 billion on the PX and CAISO RT market and racking up \$20 billion in debt by Spring of 2001, it was no longer possible for three IOUs to buy electricity from the wholesale market. As utility companies, their credit ratings were even reduced to junk status. Consequently, a wave of blackouts occurred: from June to September in 2000, CAISO in total issued 14 times of Stage 1 emergency order, 16 times of State 2. In the following November and December 2000, 4 times of Stage 1¸18 times of Stage 2, and 1 Stage 3 order were issued again. Things became more devastating in 2001, by May 2001, 127 times of Stage 1/ Stage 2 and 38 times of Stage 3 emergency orders were released. As estimated, the crisis cost between \$ 40 and \$45 billion, and it must not be hard to imagine how many people's lives were impacted.

To keep the "California Lights On", State Governor at that time, Gray Davis decided to

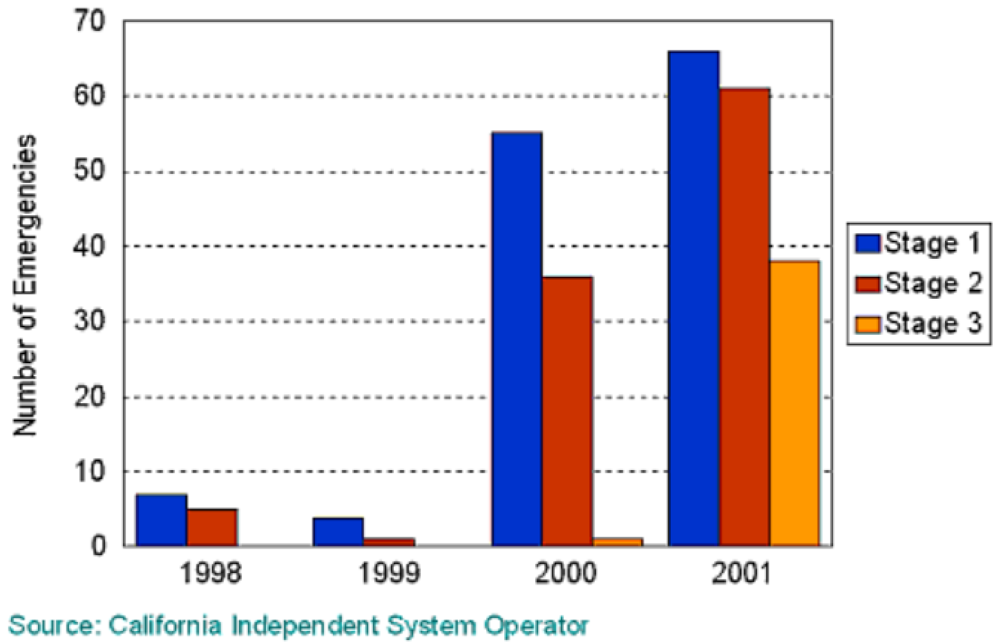

Figure 4: California's Declared Staged Power Emergencies, 1998 to May 22, 2001

grant $400 million of taxpayer money to help finance three utility companies procuring electricity in December 2000. He then approved another $10 billion signing long-term power contracts with suppliers. But this series of responses was not considered properly, not only leads to the Governor's own recall election in 2003, but also decrease state government's financial position from a surplus to a deficit. It took almost a year until late 2001 when California gradually recovered from this crisis after the federal government, state government and CAISO all stepped in and issued a batch of new measures.

What makes the August blackout different from 2001 crisis in essence?

The 2000-2001 Western Power Crisis is one of the worst energy market failures in U.S. history, leading to devastating blackouts and enormous economic loss. Several factors have been recognized as key issues that drove the failure:

- First, from 1990s to early 2000s, the free economy in California drove electricity demand to grow rapidly. However, corresponding investment in new power generation capacity had not kept pace with the increasing demand, probably out of investors' fear of innovative retail competition mechanism. According to EIA, California's generation capability decreased 2% from 1990 through 1999, while retail sales increased by 11%. This makes California's electric system vulnerable to fluctuations in out-of-state power imports or in-state generation loss. Indeed, as we see multiple power sources became less available simultaneously in 2000 summer, the initial power shortage was ignited in California.

- Second, early California restructured electricity market was not well-designed, which left room for malicious market manipulation. In the first place, splitting PX and CAISO as two entities for managing unconstrained DA transactions and RT incremental energy or congestion dispatch separately in fact created opportunity costs and efficiency loss. The uncertainty around real-time load fluctuations and transmission constraints burdened CAISO RT market and Ancillary service market, which makes them more vulnerable to the unstable market environment. Besides, the lack of long-term power contracts prevented utilities from hedging their energy purchases as well as wholesale price ahead and mitigating day-to-day swings in prices due to transient supply disruptions or demand spikes. This conversely also kept generators from making commitments to new resources as few independent power producers were willing to undertake the risk of building a plant without having a significant portion of a plant's capability committed to long-term contracts. All these provided speculation opportunities to financial agencies and trading companies.

- Third, the Commission and government's effort to deal with the electricity crisis was considered inadequate and was of great controversy. The electricity bill skyrocketed first in 2000 spring, and experts had warned of an impending energy crisis. However, Governor Gray Davis barely did anything to respond until the crisis became statewide in the summer. Additionally, from August 2000 through December 2001, the government was virtually devoid of any discussion or treatment of supplier behavior, neither did it allowed prices to motivate demand reductions. Instead, Davis signed overpriced energy contracts, which locked Californians into high electric costs for the next decade and reduced the state's financial position to a deficit. With large utilities drained their financial assets and borrowing power for procuring expensive electricity, and government depleted the state budget for stepping in and taking over as the sole electricity buyer, the energy crisis was gradually extended to a severe dual financial-electricity crisis.

In all, from hindsight, the energy crisis was caused by fundamental supply and demand imbalance, market manipulation, and was prolonged into a big financial crisis due to regulator's failure to timely intervene. However, in the August blackout incident, there is neither market manipulation nor improper regulatory interference, instead are more of preventative measures for ensuring grid stability. These in fact have nothing to do with the deregulated market faults or the electricity crisis 20 years ago. Nevertheless, to prevent similar things from happening again, the current California power system indeed need to cope with several urgent challenges.

Before providing a detailed explanation of these challenges, let's first look at a net demand plot on August 14^{th} and 15^{th}. Net demand is the difference between total demand and the sum of solar and wind generation at a moment. The shape of a 24-hour net demand plot is thus an illustration of how ISOs manage the quickly changing ramp rates of variable resources such as solar and wind.

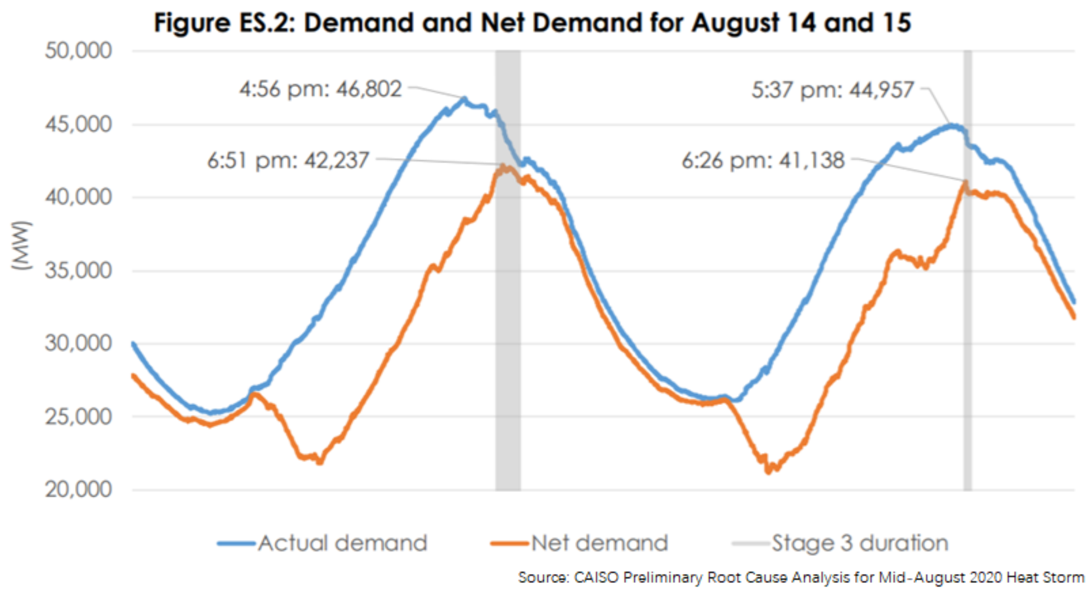

Figure 5: Demand and Net Demand curve for August 14^{th} and 15^{th}

If we briefly review the time period blackouts happened in two days, both occurred during the late afternoon, when total electricity demand reaches a relatively higher level in a day. This is also the time when CAISO need to rapidly ramp up alternative generation to compensate for solar or other variable energy resources loss (as shown in the climbing net demand curve in the plot). Therefore, CAISO not only needs to ensure sufficient reserve capacity, but also their ability to quickly start up and ramp up for maintaining grid stability. And this became a potential trigger.

Now comes the challenge: on August 14^{th}, when available solar generation decreased after sunset, CAISO was not able to call sufficient generation due to a sudden loss of a 750-MW gas generator. Further, due to inadequate system resources, neither did CAISO manage to bring online any additional resources which can supplement the reserved capacity shortage. This was then evolved to rolling blackouts. A similar story happened again on August 15^{th} when a 1000-MW of wind generator and another gas unit simultaneously cut off. Two core issues embedded are thus: lacking flexible reserves and system resource inadequacy.

- First, as California embracing its ambitious energy transition goal, there is insufficient flexibility resources reserved for compensating the intermittency of renewable energies. Historically, as the resource planner, CAISO only needs to build enough generating capacity to meet peak-hour demand, plus a reasonable reserve to account for unexpected outages. However, since the state gradually phases out its reliance on climate change-causing fossil fuels and integrating large amounts of renewable energies, the latter's inherent uncertainty now requires that a specific proportion of the installed generating capacity is flexible enough to rapidly adjust output to maintain system balance — a job that was usually fulfilled by nuclear, hydropower, and most importantly, the diminishing fossil fuel generators. This makes the current situation an awkward moment in the transition journey: there occurred a resource issue, instead of a renewable issue. Some criticized that California has moved too fast to decarbonize the state's power grid, leaving it vulnerable to conventional resources loss. Such arguments might be controversial, but one truth is beyond doubt: the current California system is short of back-up, flexible resources to handle unexpected changes. Just like the blackouts in August, after one reserved gas generator failed, seldom flexible units existed in the area ready to be called. This thus makes it more challenging for gird operators to maintain stability and balance supply-demand fluctuations.

- Second, stakeholders are also pinning the blame on CPUC's failure to plan for an adequate amount of capacity to support peak load demand. CAISO has been warning regulators about potential capacity shortfalls since August 2019. The Board of Governors claimed that CPUC should authorize a 2020 2022 power procurement plan as soon as possible to meet reliability requirements, or system resources inadequacy may appear as early in 2020. However, even CPUC quickly authorize the procurement of 3,300 MW of clean energy by 2023 in November, it was not until June this year that the 2021-2023 regional power purchase instruction was formally passed, requiring PG&E and SCE to conduct capacity planning for resource abundancy begin in 2021. Many have expressed concern that these steps do not go far enough to guarantee the future liability needs of the state are met. Indeed, on August 14^{th}, California's resource adequacy plan was broken – it did not address spiking load requirements in an extreme summer afternoon and led to serious blackout among large segments of the population. CPUC's failure to timely respond to CAISO's warning is attributable for part of these problems.

It can now be concluded that the August blackout in California was attributed to inadequate preparation for high-percentage renewable integration and scanty capacity planning. To be objective, both California's PUC and system operator CAISO should be blamed for some flaws to be corrected. Nevertheless, compared to the 2000-2001 electricity crisis which was evolved with market manipulation, these could be counted as fair challenges during the transition toward renewable energies.

Discussion

To prevent these problems from causing future blackouts and ensure a reliable transition, CAISO will now have to begin planning on future energy requirements. How much energy people may actually end up need during the hottest day in a year need to be effectively estimated. But this is not adequate, rapidly increasing amounts of variable generation like wind and solar are making system flexibility a new priority. Adding additional generating capacity solely for providing system flexibility may ultimately be needed to achieve California's 2045 100% carbon-free grid. Potential flexibility resources in the state include:

1. Hydropower or pumped-storage hydropower. Hydropower is probably the most flexible electricity-generating resource so far. It can store or deliver electricity second-to-second to meet real time energy needs. In countries with rich hydraulic resources like Austria, hydropower is acting as a grid stabilizer to support renewables sprouting. For California, where there exist massive water projects including dams, reservoirs, aqueducts and canals, pumped-storage hydropower can easily complement wind and solar generation and even address peak demands. Germany has long been using 31 pumped-storage power stations to safeguard its energy supply before wind and solar come online, and this could be a good instance California can learn from.

2. Grid Storage or Electric vehicles. Energy storage facility's role in absorbing intermittent renewable generation and flatten supply curve is indisputable, and CAISO, following FERC's Order 841, has already encouraged storage technologies to participate in the wholesale ancillary services market and energy market. These can continue to provide flexibility in the system. Additionally, EV battery as a distinct form of storage facility, was pushing ahead as another critical solution for stabilizing the grid. California already has gigawatts' worth of EV chargers, with more gigawatts coming as part of its push to electrify the transportation sector. Enabling them to export EV battery capacity, rather than simply stop charging, i.e. the dynamic V2G or V2H mode, could make them an even more valuable grid resource.

3. Demand response. As an emerging approach for increasing grid flexibility from the customer-side instead of the generation-side, demand response can be a powerful tool to support the integration of variable energy resources. For instance, switches and radios can turn buildings into thermal batteries: by simply pre-cooling or pre-heating buildings and water supplies, thermostats and hot water heaters can become amazing sources of grid flexibility. Besides, using varying market electricity prices to guide customer behaviors can also prevent noticeable inconvenience to the consumers while shedding significant loads during peak-demand hours. Indeed, costumers' conservation behaviors, or to say the curbed

demand level is recognized to have to some extent helped utilities stabilize grid and secure important operations during the August blackout. According to a post on Greentech Media, the Demand Response program participants in PG&E, SCE and SDG&E area immediately dropped 1,000 MW of interruptible load as the energy alerts kicked in. Their contribution was recognized and praised by CAISO, but admittedly, in achieving an electricity system with an extremely high share of energy from renewable sources, demand response's value as a flexibility resource needs to be further explored. Better market design and smarter retail pricing mechanism are also necessary to tap the real potential of demand response programs.

4. Green hydrogen. With all three resources above have the potential to provide second-to-second or minute-to-minute flexibility, green hydrogen could act as a flexible storage medium to alleviate seasonal fluctuations of renewable generations. After being produced from solar or wind-powered electrolyzers, green hydrogen could either be stored to deliver electricity back to the grid, i.e. Power-to-hydrogen, or be used to fuel transportation and generate heat for industrial processes. The interaction between hydrogen production facilities and the grid can thus provide long-duration flexibility for the system.

In all, as the overall resource mix evolves rapidly and new, clean technologies become an increasingly vital part, CAISO must begin to look several years out to ensure that sufficient flexible capacity is available down the road, instead of solely meeting total resource adequacy, to avoid future rolling blackouts. Either via direct mandates or through the right economic incentives, grid operators should increase the availability of flexible ramping capacity in both near-term operations and long-term planning to take full advantage of zero-emissions resources and enhance grid flexibility. After the August wildfire, this moment of grid improvement might be the perfect time to set the wheels in motion on flexibility.