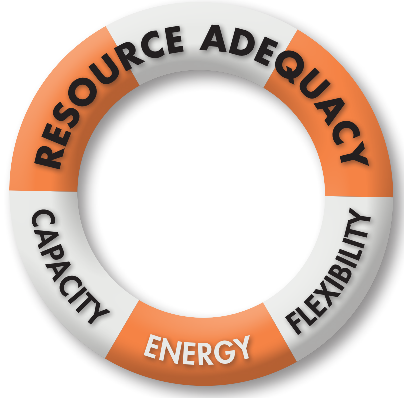
ELECTRIC POWER RESEARCH INSTITUTE

Resource Adequacy Challenges: Issues Identified Through Recent Experience in California

In Summary

- In August 2020, load shedding occurred on two days in the California power system due to supply shortages. A variety of factors contributed to this event, driven by high temperatures across the Western U.S.
- Methods to assess the adequacy of the system to meet demand are well established, but are evolving with resource mix.
- Reliability can be maintained—or even improved—with emerging resources reliability, but enhanced supply resource and customer demand models, as well as simulation tool improvements, are needed to inform evolving standards and metrics for a range of scenarios.
- A simple roadmap is provided to support adoption of new tools and methods for assessing adequacy.



Introduction

The recent events in California, where the California Independent System Operator (CAISO) called for rolling power outages (load shedding), highlights the importance of resource adequacy as the grid evolves. The outages resulted from a confluence of events but were driven in large part by sustained high temperatures across the Western Interconnection. The CAISO supply deficiency was largely due to a resource adequacy (RA) issue. As such, this briefing first describes what resource adequacy is and how it is evolving, then provides context on the CAISO event and describes the research necessary to sustain resource adequacy through the current energy transition.

Resource Adequacy

What is resource adequacy?

Reliability is considered to have two main components, one of which is adequacy. Security, also referred to as deliverability, is the other component of reliability that ensures the network facilitates power flow and maintains stability after disturbances. Resource adequacy (RA) is an assessment of whether the current or projected resource mix is sufficient to meet capacity and energy needs for a particular power system. The resource mix refers to the mix of supply-side generation, such as solar paired with energy storage, nuclear, gas, etc., and demand-side flexibility, such as demand response and energy efficiency. RA assessments are used to identify potential shortfalls in the availability of resources across different time frames, from long-term planning (5 to 20+ years) to seasonal and day-ahead assessments. As planning time before stressful grid events shrinks to months, days, or hours, options to address identified shortfalls become fewer and more expensive.

Read More

CIGRE, "*The future of reliability–Definition of reliability in light of new developments in various devices and services which offer customers and system operators new levels of flexibility*", Technical Brochure No. 715, 2018.

North American Electric Reliability Corporation (NERC), "*Definition: Adequate Level of Reliability for the Bulk Electric System*", March 2013, (link).

Electric Power Research Institute, "*Capacity and Energy in an Integrated Grid*", EPRI, Palo Alto, CA: 2015. 3002006692.

Key Terms

Energy, measured in kilowatt-hours (kWh), is required to operate consumers' lighting, equipment, appliances and other devices, often called loads. Energy is measured over a period of time.

Demand is a measure of power in kilowatts (kW) or megawatts (MW), of how much energy a consumer (or group of consumers) requires at a specific point in time. Though demand can be measured at any point in time, the peak demand level is often an important characteristic of a load, a premises, or an entire power system.

Capacity is the maximum capability to supply and deliver a given level of energy demand at any point in time. **Supply** capacity describes networks of generators designed to serve load as it varies from minimum to maximum values over time. **Delivery** capacity is determined by the design and operation of the power transmission and distribution systems.

Resources are a mix of supply-side power generation and storage facilities and all demand-side programs, such as energy efficiency and demand-response programs to meet customer demand.

How is adequacy measured?

Estimating RA is a critical step in ensuring a reliable power system. As part of a recent RA research effort, EPRI counted over 33 different RA metrics, with varying scopes and complexities in the way they are calculated and the insights they provide.

At the simplest level, a *planning reserve margin*, (the amount by which available supply exceeds projected annual peak load less demand side resources), can be used to screen for adequacy. A nominal target value is about 15%, but adequacy of a system at any reserve level is dependent on the size and composition of its resources, its ties with neighboring systems, and the characteristics of its load.

A range of more-complex, probabilistic metrics and methods customize this value and provide critical insights into the likelihood of having sufficient resources to meet demand under projected conditions.

RA metrics have been used since the 1940s, with much debate as to what should be considered "adequate." By 1957, a criterion of limiting loss of load expectation to less than "one day in ten years" became popular.

Other common measures for resource adequacy include loss of load hours (LOLH), loss of load expectation (LOLE) and expected unserved energy (EUE) (see further reading). As an example, LOLH is often limited to 2.4 hours per year, a probabilistic interpretation of "one day in ten years." Note that the interpretation and calculation for "one day in ten years" is often a source of confusion, with different interpretations whether calculated as one event, one hour, one day, etc.

These metrics are calculated by considering a range of factors that determine the likelihood of resources not being available to meet demand and of the projected demand levels. Various methods have been developed to determine these metrics for any given power system, ranging from relatively simple models to detailed simulations.

Read More

Resource Adequacy: History and Catalog of Metrics, EPRI, Palo Alto, CA: 2016. 3002013734.

What does it mean to have adequate resources?

RA criteria are probabilistic. That means that a system that meets RA criteria is expected to have sufficient supply and demand-side resources to meet peak system demand, with a certain level of confidence. From modeling the range of expected conditions, a system that is planned for adequacy may still experience temporary and rare periods of scarcity, some of which may lead to involuntary load shedding if the same conditions arise in real-time operations. Load shedding is the interruption of customer load sufficient to balance supply and demand and to ensure available resources sufficient to respond to unforeseen disturbances or contingencies.

Adequacy criteria themselves recognize that some periods of scarcity may occur, with very low probability. Typically, these scarcity events are probable only during a confluence of conditions that would have low probability in combination. These combinations of conditions are considered so rare that planning to meet demand during these 'very rare' events is not cost-justifiable. In fact, some systems derive their adequacy criterion economically, searching for the limit of cost-justification. Whether searching for an optimal level of adequacy or projecting resource needs to meet an adequacy target, it is critical that a valid RA assessment consider a realistic range of conditions, some being beyond past experience.

It should be noted that loss of load resulting from external factors such as storm damage, wildfires, or other natural disasters that interrupt delivery of power are not normally considered in resource adequacy.

What assumptions are made about generating capacity availability in resource adequacy?

Generators of all types may fail, even during periods of high demand. Adequacy studies account for this when considering how resources contribute to meeting demand. Traditionally, load projections and generator forced outages or partial deratings were the primary drivers in adequacy studies. Typical values for availability (the opposite of outages and derating) range from 85% to 95%, depending on the type of power plant, operational history, age, and climate conditions. RA assessments assume generators are available unless forced out or on planned maintenance. Load may also be varied across a range of expected weather and economic conditions.

Who is responsible for resource adequacy?

Setting adequacy requirements, assessing adequacy, procuring capacity, and contracting are distinct tasks that are intertwined and related to ensuring sufficient capacity. Adequacy standards and requirements normally originate in laws, regulations, or license agreements. State public utility commissions and other regulators may hold RA proceedings and approve requirements, standards, and the actions necessary to secure adequacy.

RA assessments are conducted by a variety of entities. In regions with centralized wholesale markets, they may be conducted by independent system operators (ISOs), transmission system operators (TSOs), regional security coordinators (in Europe), or regulators, irrespective of who may be responsible for ensuring adequacy. In other regions, utilities are typically responsible for assessing and ensuring adequate supply themselves, using methods and criteria subject to approval by regulatory and other authorities.

In the structured-market areas, there are three primary classifications of methods by which capacity is secured: 1) centralized capacity markets (e.g. PJM), 2) decentralized or regional capacity procurement (e.g. California) and 3) no explicit capacity markets ("Energy Only" markets such as in Texas).

How is resource adequacy changing?

Until recently, RA in most systems referred to having sufficient planned capacity (traditionally, dispatchable generation) to meet the expected peak demand over a study period, which may range from months to years or decades. Several factors are impacting the ability of planners to assess resource adequacy.

Changing Generation Mix. There are more types of power generation, from traditional thermal generation, like coal, nuclear and natural gas-fired generation, to weather-dependent renewable generation such as hydropower, wind, and solar. These resources vary widely in their ability to produce electricity when demand is high. Demand-side resources, such as controllable or deferrable demand can contribute to RA, and battery storage is a growing resource, though its RA contribution is more complex to evaluate than for other resources.

Changing Demand Characteristics. Improving energy efficiency affects future projections of energy demand. Load shapes are also changing, which may create new types of stressful periods. For example, large net-load ramps may stress systems if generators cannot respond quickly, even if there is sufficient capacity. Electrification of various parts of the economy may change load shapes and magnitudes, while also providing additional demand-side flexibility. Climate change may also impact demand and needs to be considered in studies with longer horizons.

Energy-Limited Resources. The evolution of RA assessment is also shifting toward both available capacity and energy supply. Some modern resources, like batteries and demand response, have limits to their energy capability, so these factors also need to be accounted for. Hydro-dominated systems have long seen this dual need for capacity and energy.

To produce a more accurate picture, RA models are becoming more sophisticated by including all the above elements, as well as transmission capacity, fuel availability, and other factors. The very nature of what constitutes an adequate system is increasingly an open question in the era of flexible demand. These changes are discussed in the later section on challenges.

Read More

North American Electric Reliability Corporation (NERC), Generating Availability Data System (GADS), (link).

European Network of Transmission System Operators for Electricity (ENTSO-E), Mid-term Adequacy Forecast, (link).

National Grid Electricity System Operator, Electricity Market Reform, (link).

Electric Power Research Institute, *Considering Generator Cycling in Resource Adequacy,* EPRI: 2018. 3002013488.

Electric Power Research Institute, *Developing a Framework for Integrated Energy Network Planning (IEN-P),* EPRI: 2018. 3002010821.

What role do renewables play in providing capacity?

The ability of hydropower, wind, and solar power plants to produce energy varies across time, which impacts their contribution to RA. This requires analyzing the likelihood that these resources will generate power to contribute to meeting demand, based on sufficiently long periods of historical weather data (adjusted for climate change if necessary).

Power system resource planners in hydro-based systems are familiar with the probabilistic approaches often used to assess the risk of low precipitation on supply during peak periods. This has resulted in advanced methodologies that incorporate energy requirements into adequacy studies for such systems.

In systems where peaks happen during the daytime (typically summer-peaking systems), solar generation may help meet mid-day and early evening peak demand. But solar provides little or no support for the remaining later-evening peak, while creating a steep ramp in net load. So, while increasing amounts of solar contribute capacity to reduce the mid-day peak, the increases may result in shifting the peaking period to the evening, when zero or low solar is available. This results in a declining capacity contribution from solar resources.

Wind generation behaves and contributes differently from solar. Seasonal, diurnal, and multi-day weather events drive the extent to which wind generation is coincident with peak energy needs. In systems where there is a high correlation, the capacity contribution of additional wind generation does not decline as rapidly as for solar.

The degree to which renewable availability and production coincide with system-level scarcity determines the capacity contribution of renewable resources. The availability of renewable equipment is often relatively high with less likelihood of an entire plant failing, but the availability of the underlying weather-dependent energy source is more uncertain. Therefore, detailed methods such as Effective Load Carrying Capability (ELCC) have been developed to assess their contribution.

Read More

Electric Power Research Institute, *Program on Technology Innovation: Capacity Adequacy and Variable Generation*, Palo Alto, CA: 2016. 3002007018.

North American Electric Reliability Corporation, *Methods to Model and Calculate Capacity Contributions of Variable Generation for Resource Adequacy Planning*, March 2011.

What about energy storage?

Pumped storage hydro (PSH) and battery storage contribute to RA. PSH reservoirs are typically large enough to allow for eight or more hours of continuous output at rated capacity. Historically, analysts have made the assumption that PSH can be operated to ensure that their upper reservoirs are full when a predicted scarcity event approaches. Therefore, they are largely treated in the same way as conventional generators for the purposes of RA, with only equipment failures considered.

Battery durations typically range from one to four hours, with newer installations trending towards longer durations. For batteries with shorter durations, their ability to contribute sustainably to the peak load is heavily dependent on the duration, shape, and certainty associated with scarcity periods. For shorter battery durations, the risk of stored energy being insufficient to deliver capacity during stressful conditions increases, resulting in de-rating. Current assessment methods may preclude shorter duration batteries from RA credit, or significantly reduce their assumed contribution. This is an area of active research with methods involving chronological modeling being developed to assess battery contributions to adequacy, as well as hybrid resources, e.g., solar-plus-storage.

Read More

Electric Power Research Institute, *Energy Storage Capacity Value Estimation*, Palo Alto, CA: 2019. 3002103491.

How do imports and exports affect resource adequacy?

RA can be estimated for large geographic regions (e.g. Europe) or for a specific administrative or bulk system operator footprint within a region. A system that is part of a wider interconnection has transmission interties (AC or HVDC) with neighboring systems. The degree to which energy imports and exports impact the assessment of adequacy of an interconnected system depends on:

- Certainty of, and availability of, the capacity located in the sending footprint and the reliability of the transmission network transferring the power to the interface.
- The likelihood of coincident scarcity conditions occurring in both sending and receiving systems.
- Contractual obligations that may hinder or fail to promote local system operations, balancing, resource sharing, and priorities.

Several studies have demonstrated that assessing capacity adequacy over a wider footprint reduces the generation capacity required, when compared to smaller subdivisions of footprints, under fully adequate transmission assumptions. However, alignment between regulatory authority and grid regional boundaries is rare.

Forecasts of non-firm imports across AC-connected areas may have significant errors compared to firm, scheduled imports. Non-firm contracts are more likely to be curtailed due to grid conditions. For RA, a prudent approach assumes the availability of generation outside the territory is grounded in firm operational experiences and contractual agreements.

Is the risk of capacity shortages only during the peak demand period?

While the annual peak demand is most likely the period of highest risk, capacity shortfalls may occur at other high daily peaks and in the period surrounding the peak hours. Some systems experience peaks in both the winter and the summer, reflecting heating and cooling load.

Increasingly, the greatest likelihood of a capacity shortage occurs at the peak net-load interval. Net load represents the “net” demand not served by wind and solar generation and which must be met by traditional resources. Similarly, risk can commonly occur during spring and fall when maintenance outages typically occur.

As a result, modelling and assessing RA is often conducted with hourly simulations of many scenarios, rather than just the daily peak. The outage in California is a good example of a shortage occurring at a time that did not coincide with the typical peak demand period of either day or year.

Read More

Electric Power Research Institute, *Program on Technology Innovation: Capacity Adequacy and Variable Generation*, Palo Alto, CA: 2016. 3002007018.

What happens when a real-time capacity shortage is declared?

When system operators forecast a capacity shortage risk, they may take several actions to address it, including:

1. Days ahead, market notices about the expected grid conditions are issued to market participants.
2. Plants undergoing non-essential, planned outages are recalled into service, if possible, and new outages are deferred.
3. Support from neighboring regions may be requested.
4. Public conservation notices may be issued depending on the magnitude of the forecasted shortfall.
5. Resources contracted for "capacity adequacy" are notified and resources that take a comparatively long time to come online are instructed to be online.
6. Distribution network operators may be notified of the need to implement conservation voltage reduction.

These actions are updated as conditions evolve. At the day-ahead and intra-day stages, forecasts are regularly updated to reflect changing demand and renewable production positions. If available generation, storage, import, and demand-response capacity is insufficient to meet operating reserve plus forecasted demand, scarcity pricing may be invoked. In scarcity periods, energy-market prices often increase reflecting the tightened supply/ demand balance and reach market ceiling levels (e.g. 9,000 $/MWh, 1,000 €/MWh).

As a real-time scarcity event worsens, the available mitigating actions may reduce to only load shedding. Expected production, demand schedules, and grid topology are analyzed for congestion and energy deliverability issues. Should an operational threshold be reached (typically a shortfall of operating reserves), coordinated, rolling, involuntary interruption of loads is conducted, for the duration of the scarcity event, known as load shedding. The operational goal is to maintain grid cohesion by holding sufficient operating reserves.

Read More

North American Electric Reliability Corporation (NERC). Standard EOP-003-1—Load Shedding Plans, (link).

August 14-15th Californian Capacity Adequacy Event

A widespread heat wave across the west occurred in mid-August 2020, as shown in Figure 1. While more details may emerge, it appears that a confluence of the following factors led to the supply shortage:

1. High load across the west resulting in lower than expected imports
2. Gas power plant outages and deratings due to high temperatures
3. Relatively low hydro output

All these occurred during evening net-load peak periods when solar output is low or zero and demand was relatively high. Operators would have foreseen a likely shortfall in operating reserves, and the need for load shedding. This is the type of event that newer RA assessments are trying to capture. The rest of this section describes what happened based on currently available data, how it compared to projections, and what this tells us about resource adequacy in a power system with high penetration of renewable resources, like California.

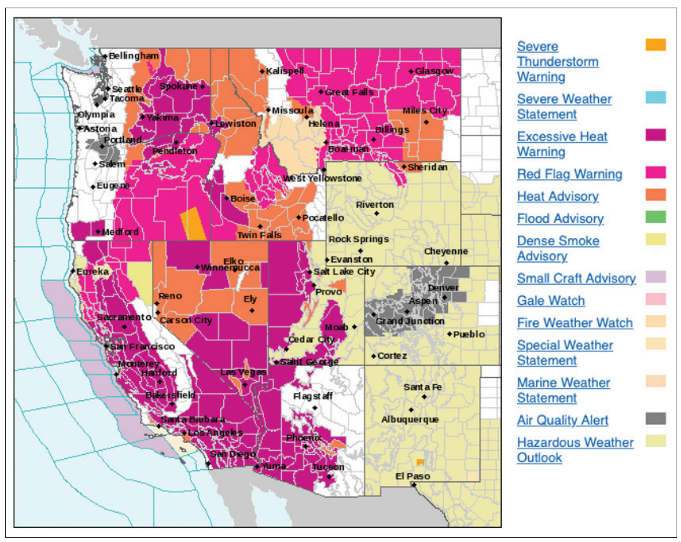


Figure 1. Map showing weather alerts across the Western United States on August 14, 2020

What happened in the recent CA event?

On August 14, 2020, the first day of rolling blackouts, the real-time peak demand was 46,777 MW at 17:00 Pacific Time. The day-ahead load forecast was accurate to 1.1%.

At 14:56, 475 MW of gas generation became unavailable. As shown in Figure 2, imports to the CAISO decreased steadily from morning until 15:20, when CAISO issued a Stage 2 Emergency notification calling for voluntary load interruptions. No substantial restrictions on import limits were evident at the CAISO interface.

Although imports steadily rose over the next several hours, as shown in Figure 2, they were insufficient to offset the decrease in solar PV as the sun set. At 18:36, CAISO was unable to maintain its load-plus-operating-reserve obligation, and thus issued a Stage 3 Emergency notice, which shed 500 MW of load; at 18:46 an additional 500 MW was shed. Orders to restore load were issued at 19:56.

On August 15, peak demand was lower than on the prior day, 44,913 MW at 18:00. From 16:10 to 17:10 wind generation ramped up approximately 1,200 MW and then back down the same amount over the next 50 minutes. At 18:13, a gas plant quickly ramped down 250 MW due to an incorrect scheduling instruction from the utility scheduling coordinator. At 18:25, CAISO issued a Stage 3 Emergency notice for 470 MW of load shedding for 22 minutes because reserve was deficient.

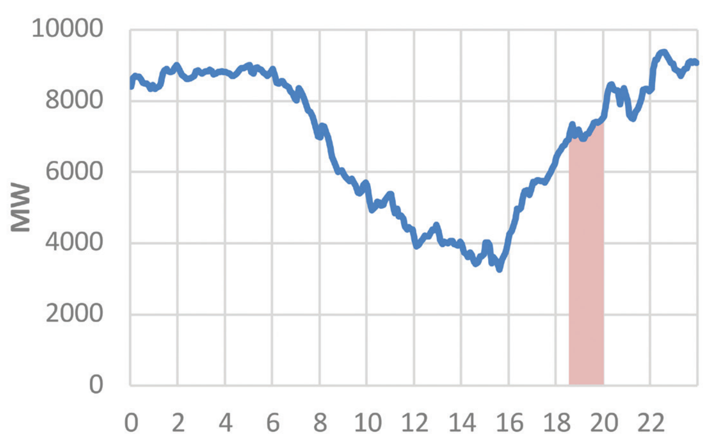


Figure 2. Imports to CAISO system during August 14, 2020, with load shedding period highlighted

What were the projections in the time leading up to the events?

At the September 2019 CAISO Governing Board Meeting, the CAISO recognized that the confluence of generator retirements in the past several years, and the fact that solar capacity that has been added declines at sunset, resulted in the need for increasing imports to balance the system. In May 2020, the CAISO concluded in its Summer Loads and Resources Assessment that:

> *"With lower than normal hydro conditions, the CAISO may have to rely more heavily on imports from neighboring [balancing authorities] during the CAISO summer peak hours. However, if a heat wave occurs that impacts a broader area than the CAISO, the availability of surplus energy to import into the CAISO could be diminished."*

During the period from August 14-18, a very broad heat wave covered the Western U.S. and imports were limited, and in the same report, sensitivity cases reflected the potential for reduced imports, showing a 1.6% probability that a shortfall would lead to load shedding. While those cases do not exactly match the scenario that resulted, the methods described in the previous sections did represent a potential shortfall resulting in load shedding. It should be noted that demand did not exceed the one-in-five (20% probability) load forecast – the highest-risk load scenario studied.

The 2020 Summer Assessment also showed a total of 1,991 MW of recently retired and mothballed generation resources (6/1/2019 to 6/1/2020), mostly natural gas. During the same period, 3,423 MW generation was added to the system, of which 1,478 MW was natural gas-fired resources.

How did renewables perform compared to expectations?

Renewables are included in the CAISO RA studies, which featured hourly modeling. As such, their contribution to overall system peak, as well as the fact that solar would not have been available after sunset, are both accounted for. Initial indications are that renewables performed as expected and did not precipitate a scarcity event.

Solar PV resources appear to have contributed more energy to meet the absolute daily peaks than planned. They were producing more than double the capacity assumed in CAISO's 2020 Summer Resources Assessment at 17:00 (daily peak) on Aug 14. PV ramped down significantly over the next few hours as the sun set.

Wind provided anywhere from 45-65% of accredited capacity during the two-hour August 14 load shed. Wind output was higher during the August 15 load shed event (90–120% of accredited output), but the output was volatile, ramping up 1,200 MW and then down 1,200 MW in the hours just prior to the load shed event. This may have caused some additional uncertainty for operators.

The August 15 renewables trend from the CAISO daily outlook site on Saturday (Figure 3), shows a decline in wind generation concurrent with the solar decline for the hour preceding the 18:28 interruption, which would have added more pressure on the system's ramping capability (though it is not clear whether ramping capability was an issue during the period). During the interruption period, wind energy was rising at about 825 MW/hour, relieving some of this pressure and contributing to balancing supply and demand.

What about natural gas and hydro?

Natural gas and hydro resources are counted upon to provide a large amount of the resource adequacy in California. Gas power output peaked at approximately 25.5 GW, while the Summer Resources Assessment assumed 29 GW of capacity would be available during the summer (that study would have assumed outages when calculating adequacy, such that a portion of those resources would have been expected to be on outage). Specific numbers for gas outages were not available at the time of this writing, but initial indications are that there were some derating and/or outages, while gas was also likely to be providing spinning reserves during this time, in the event of a contingency.

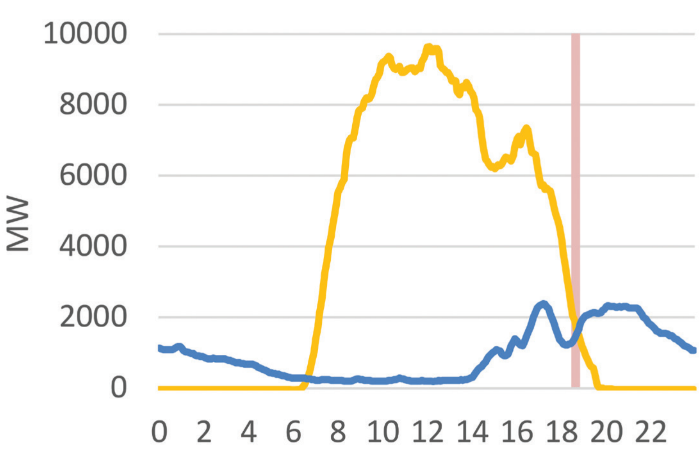


Figure 3. Wind (blue) and solar (yellow) power output in CAISO on August 15th, with load shedding period shown in red

2020 has been a low year for hydro production in general, and initial indications are that hydro generation was marginally lower than might have been expected in studies. At least part of this would reflect hydro output declining over the summer as available water resources are diminished, while other factors such as reserves provision may also have contributed.

How did imports contribute?

The CAISO 2020 Summer Loads and Resources Assessment (May 2020) was a routine operational RA assessment to evaluate how to operate the system under the weather and resource contitions foreseeable for the summer ahead. It relied on a base case assumption that available import energy, which is assumed to vary depending on load, would be approximately 10,500 MW at the load level observed during the periods when load was shed. A sensitivity case reduced this amount to about 9,000 MW.

The actual imports during the two outage periods varied between approximately 6.9 GW at the start of the period in question and 8.5 GW by the end of the event. Therefore, imports were below the base case imports, particularly during the early periods of the outage, and closer to, but still lower than, the sensitivity case. That sensitivity case did show a significant increase in the likelihood of shortages, with 31 of 2000 simulations (1.6%) showing load shedding at that assumed import level.

How did energy storage perform?

California has about 320 MW of utility-scale storage capacity according to the Wood Mackenzie database. During the interruption days, the storage ranged from discharging at 310 MW to charging at 179 MW. Near the end of each interruption, the net storage behavior shifted from discharging to charging. This may have been a function of load following (indicating that the system was stabilizing), delayed public notice, or other factors unrelated to what was happening at the system level. It is not clear why storage charged during this period, but it may not have been related to the system operations needs and might have followed a local signal (such as time-of-day pricing). There are also a growing number of customer-sited battery storage resources in California that are not included in these numbers, nor is their charge/discharge behavior measured. These may have provided benefit to the CAISO system, depending on customer objectives. A forthcoming EPRI paper examines potential scenarios for residential battery storage behavior and potential alignment with power system needs.

How effective were demand response and public conservation measures in preventing further load shed?

At 17:15 on August 14, CAISO dispatched 800 MW of demand response to help maintain supply balance. While CAISO has not yet commented on the exact capacity provided, public statements have praised the contributions of demand resources during the event. Further, on August 13 and 14, the CAISO issued Flex Alerts to encourage energy conservation that did not avert rolling interruptions on August 14 and 15. However, by Monday, August 17, the conservation measures helped avert further interruptions, and on Tuesday, even after a one-hour notice of potential grid interruptions, they were averted.

Did COVID-19 play a role in creating conditions for the event?

The actual DA forecast (46,258 MW) on August 14 was 1,517 MW lower than the one in five peak forecast (47,775 MW) from the Summer Assessment, and the actual peak load was 46,777 MW, within 1.1% of the DA forecast. As such, it is not likely that the load was higher than expected either several months or a day in advance. On August 15, the peak load was even lower.

For these reasons, it is not likely that the COVID-19 virus caused the electricity demand to be out of the expected range. It would not have been projected ahead of time, though could have been considered in the more recent May assessment.

What is convergence, or virtual, bidding and how does it impact operations during scarcity events?

Convergence bidding, a CAISO term for virtual bidding, refers to offers to buy or sell day ahead (DA) energy as virtual demand or supply, without backing by physical need to use or ability to produce the power. These are automatically resolved in the form of real time (RT) energy. Their purpose is to help manage market risk by making it possible for energy traders to take long or short positions, based on their expectation about differences between the DA and RT energy prices. The social benefits are to help mitigate the financial risk to the "physical" market players and their customers, to make the differences between the DA and RT energy prices more transparent, and to cause them to converge toward the same value. These transactions mimic a hedging option against differences between the DA and RT energy prices at the same or different locations.

In the absence of hedging options, the market may be incomplete and open to gaming, which can make system balancing difficult. Especially during scarcity events, physical trading may become illiquid in certain locations and to the extent that it is predictable, virtual bidding may adversely affect trading and system operations. By 16 Aug, the CAISO "determined that convergence bidding is detrimentally affecting the ISO's ability to maintain reliable grid operations" and suspended it from 18 through 22 Aug.

Can insights from this event inform efforts to decarbonize buildings and transport through electrification?

In the days after the event, there was a notable reduction in demand at peak times, compared to what would have typically been expected; some of this reduction is likely to have been the use of coordinated programs leveraging technology that can aggregately reduce demand, such as smart thermostats, smart electric vehicle charging, etc. Such resources may become a larger part of the response to scarcity events in the future.

Therefore, lessons learned here will be important to understand to ensure resource adequacy is maintained. Two of the key future resources that could be used in the future to manage RA may be the use of buildings and transportation. In parallel with this paper, EPRI has also released a paper focused on how energy storage and load could contribute to meeting RA requirements.

Read More

Electric Power Research Institute, *Program on Technology Innovation: Residential Battery Storage Operations in Rolling Blackouts: Analyzing Opportunities to Align Customer and Power System Needs*, Palo Alto, CA: 2020. 3002019991.

What does EPRI see as the main challenges to ensuring resource adequacy?

EPRI has ongoing research in this area, and recent events reiterated the importance of such developments. What follows is a selection of some of the most relevant areas of research related to resource adequacy.

Resource Modeling

Continued evolution of how resources are quantitatively modelled in the adequacy assessment process is essential to proper planning and operations as resource mixes change rapidly around the world. Basic assumptions and approaches to modelling both new technologies (e.g. renewables, storage and distributed resources) and conventional resources whose operational profile is changing substantially (e.g. combined-cycle gas turbines (CCGTs), nuclear) may need to be adapted to the operations expected over the horizon of the RA study.

The California event highlights the scrutiny of assumptions underpinning the representation of certain resource classes such as renewables, imports, and distributed resources in particular. Building new models or adjusting existing models for these resources and their availability is necessary, but should balance with a forward-looking approach that captures how such resources may behave in the future, with the use of historical performance data where available.

The goals of this research are to understand of the physical capabilities of existing and emerging resources and to model likely availability given competing and changing use cases

Customer Demand

Consumer demand for electricity is changing, as increasingly sophisticated, customizable technology and new behaviors emerge in response to new incentives. Increased electrification of heat and transport, particularly, load control through smart thermostats and water heating, building controls, flexible industrial loads (e.g. water pumping), onsite generation, storage, and the impacts of tariffs or retail incentives all interact. Their interaction makes identifying firm demand, which would be shed only involuntarily, and flexible demand, which might voluntarily contribute to balancing the system, important factors in adequacy studies. This will require more-detailed future customer demand profiles.

It is likely that flexible demand's role is increasingly important for mitigating events such as those observed in California, as methods improve and the market evolves. Operators need additional demand components to be forecast accurately, and their contribution to meeting resource adequacy better quantified, thus ensuring they can mitigate scarcity.

Therefore, a mind shift is required in how the industry thinks about demand contributions to resource adequacy, moving from RA answering the question "are there enough generators to meet expected demand, with some target level of certainty?" to "can supply and demand find balance without shedding load involuntarily, with some target level of certainty?"

This new question raises demand's role as equal to supply in finding balance, the need to separate firm load and flexible demand, and the RA trilemma of capacity, energy, and flexibility.

EPRI is performing ongoing work in this area, examining adequacy contributions of various demand-side resources, and assessing the need for studies to consider such demand.

The goals of this research are to envision future customer demand and net demand from the grid, with electrification, customer-owned generation, and new tariff structure, and the ability of emerging resources to support resource adequacy needs. The second goal is to recast the RA question as one of finding adequate supply-demand equilibrium, rather than sufficiency in the supply capacity.

Developing Planning Scenarios

As both supply and demand become more variable and uncertain, future scenarios may occur across a broader range of conditions. Planners need abilities to study the set of scenarios that represent the distribution of uncertainties affecting the economics or efficacy of investments and/or the methods of operation.

As an example, for the California case, this may mean paying closer attention to imports and demand in neighboring regions. Scenarios also need to be built reflecting future conditions envisioned with climate change in mind, not merely sampling from historical years. A robust scenario set reflects future outcomes sufficiently for describing meaningful insights to decision makers when procuring or approving the procurement of supply or demand side capacity.

The goal of this research is to create scenarios that result in insightful outcomes for adequacy studies, upon which recommendations for decisions related to future systems can be based.

Standards, Guidelines, and Criteria

The front line of defense for safe and reliable electric power is agreement on standards and guidelines, shepherded by technical expertise. EPRI and its member utilities collaborate on evaluating reliability metrics that consider extreme events, new and emerging resources and increased consideration of demand side resources. These need to be developed and applied in a manner that accurately reflects the risk, and criteria set to ensure that adequacy is maintained at levels that can be justified.

The goal is to understand which measures best reflect adequacy and other related risks, and what appropriate levels of resource adequacy entail.

Simulation Tools

As power systems evolve, the challenge and importance of understanding them is imperative. Simulation tools may address more of these complexities in order to ensure that the goal of RA assessment is met. This includes chronological modeling (e.g. moving to hourly or even 5-minute models), improved representation of demand-side resources and other emerging technologies, appropriate representation of operational decisions such as storage charging or imports, and the ability to produce more insightful metrics and analysis. Such tools should identify how different mitigating options can address shortfalls, while recognizing how operations and markets may evolve.

Hourly modeling in California recognizes the contribution of renewables, while CAISO has also assessed flexibility issues in its Flexible Resource Adequacy construct. This construct assesses the ramping capability of the system and ensures capacity is procured that is sufficient to meet projected ramps, as well as typical capacity to meet demand. Such assessments will need to continue to evolve to ensure that, not just capacity, but flexibility and energy are sufficient in a system when assessing resource adequacy. EPRI has recently worked to support CAISO in studying this flexibility issue[1].

Simulation tools may well represent and integrate diverse resources and events for planners, but also need to help their audience (executives, public interests, and regulators) understand what is happening and what do about it. EPRI is working to enable simulation tools to provide insightful information that can assist assists decision makers to explore alternative futures.

The goal of this research is to create tools to model systems with the requisite level of detail to measure supply shortfall risk with sufficient accuracy, and to provide actionable information based on detailed simulation models that is explainable to decision makers.

A Simple Roadmap to Address Emerging Resource Adequacy Challenges

EPRI actively researches RA topics and has developed a detailed understanding of the issues. To address these, resource planners, regulators, and power-sector stakeholders can follow the following simplified roadmap to unlock capacity from the grid's resources that will be needed now and into the future.

The roadmap is divided into three phases of action: Right Now, Next, and Then, each with a suggested action for resource planning groups. The effectiveness of each action depends on the unique current and future situations of each grid.

Right Now

- Tools and Methods: Adopt methods and study tools that capture risk across the full study period, not just at peak (i.e., hourly models).
- Scenarios: Choose demand and weather profiles that cover multiple years and are representative of the best estimate of future expected conditions. They may be different from historically observed conditions.
- Resources: Gather data and begin to use new methods to assess RA contributions from emerging technologies including renewables, storage and hybrid power plants, leveraging the latest resource models.

[1] See Electric Power Research Institute, *Flexibility Assessment for the California ISO: Evaluating Flexibility Needs and Systemwide Feasible Installed Flexible Capacity*, EPRI: 2020. 3002013725.

Next

- Tools: Include flexibility considerations in planning and expansion models to inform investment.
- Distributed Resources: Account for distributed resource RA contributions, considering local limits on their ability to support the system, as well as the unique characteristics of these devices (e.g., rooftop PV, batteries, electric vehicles, etc.)
- Customer Demand: Develop models of 'non-firm' grid interconnection options for assets that limit export during pre-defined conditions.

Then

- Standards: Adopt a risk-based probabilistic approach to grid and resource expansion.
- Valuation: Plan for an increased exchange of grid services between distribution and transmission.
- Energy Systems Integration: Assess the interaction of other energy systems, including heat, transportation, etc., in electric system resource adequacy, both in terms of the demand due to increased electrification and the ability of these systems to provide flexibility and capacity.

Next Steps/Ongoing EPRI Research

EPRI ongoing research projects are evaluating several of the topics discussed above. Those projects include:

Transmission Operations and Planning (EPRI Programs 39, 40, and 173)

- Development of resource adequacy metrics, methods and tools to address issues relating to changing resource mix, including renewables, distributed energy resources, storage and customer participation
- Resource adequacy and flexibility assessment guidelines website to describe current and future resource adequacy assessment methods
- Market operations and design related to procurement of capacity and flexibility services to maintain a reliable, affordable grid
- Risk-based methods for assessing transmission reliability and investigation of coordinated generation and transmission planning approaches
- Development and demonstration of methods to assess operating reserves and operational planning methods that ensure supply-demand balance

Energy Systems and Climate Analysis (EPRI Programs 178 and 201)

- Integrated energy network planning focused on closer integration of generation, transmission and distribution system planning to ensure available resources can meet load reliably.
- Electric Generation Expansion Analysis System (EGEAS) – EPRI-licensed software used by electric companies and state agencies to conduct capacity expansion and production cost modeling for resource planning.
- Developing approaches to account for the impact of natural gas fuel and other contingencies on electric sector resource adequacy (joint with Transmission Operations and Planning).
- Analysis of capacity mixes that achieve hourly resource adequacy under high variable renewable penetration using EPRI's US-REGEN tool.
- Assessment of inter-annual variability in renewable resources and the implications for capacity/balancing needs.
- Projections of future electrification and the potential to shave peak demand through controllable load.

Contact Information

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The Electric Power Research Institute, Inc. (EPRI, www.epri.com) conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public. An independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, affordability, health, safety and the environment. EPRI also provides technology, policy and economic analyses to drive long-range research and development planning, and supports research in emerging technologies. EPRI members represent 90% of the electricity generated and delivered in the United States with international participation extending to nearly 40 countries. EPRI's principal offices and laboratories are located in Palo Alto, Calif.; Charlotte, N.C.; Knoxville, Tenn.; Dallas, Texas; Lenox, Mass.; and Washington, D.C.

Together... Shaping the Future of Electricity

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