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Power Outage Rapid Response Toolkit

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A list of power grid outage experts is available upon request. Please contact RAP and the authors for more information.

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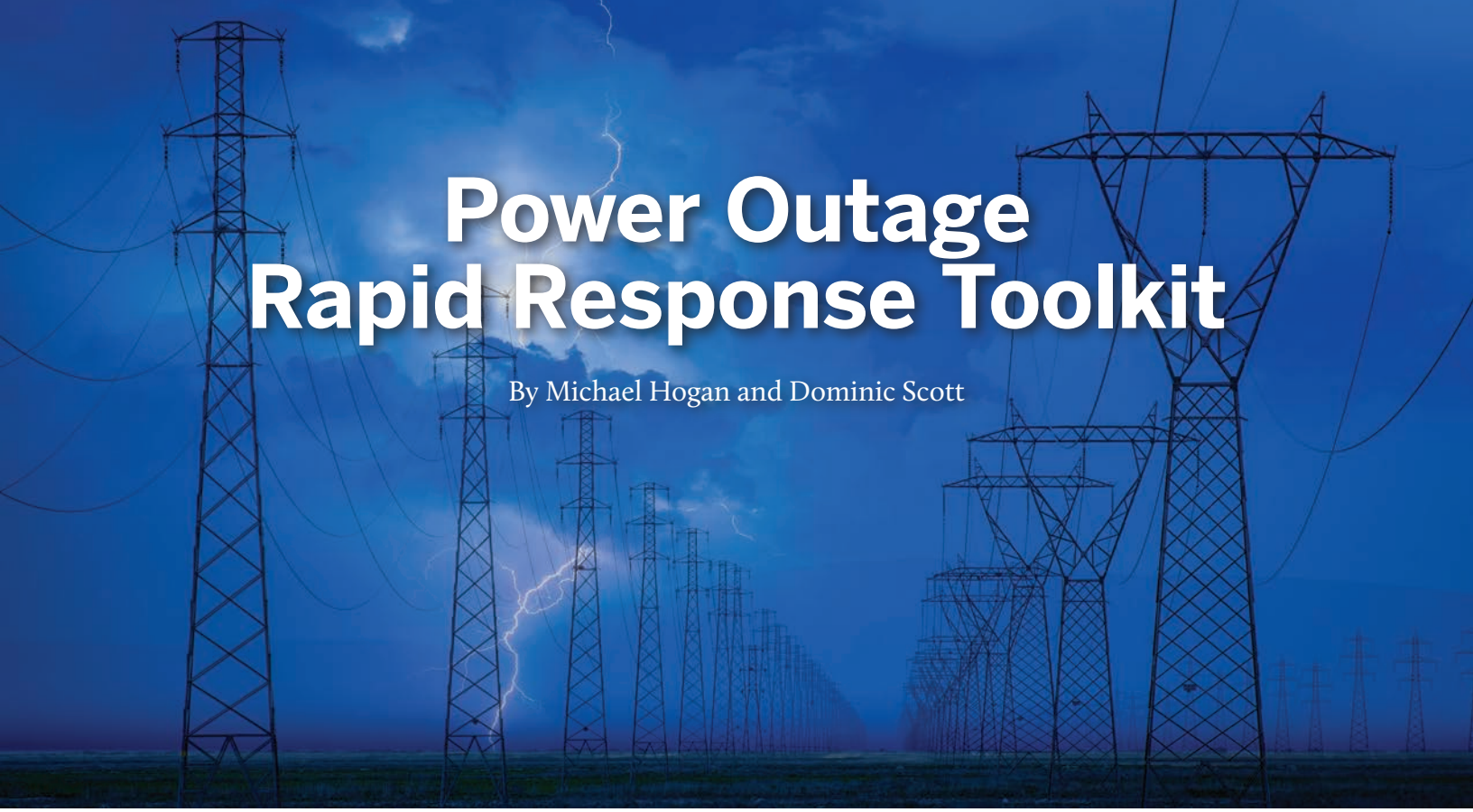

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Introduction

Interruptions in electricity supply – 'the lights going out' – make for arresting headlines and capture public attention. Yet it is strikingly rare for any kind of generation shortfalls to trigger **blackouts**: major **reliability** events are nearly always the result of grid failure incidents, such as wires frying or being damaged by trees. Furthermore, none of the recent events which have occurred in markets with high shares of renewables have been caused by over-reliance on renewables to provide sufficient electricity supplies. Nevertheless, the fossil energy industry has a track record of seizing on any opportunity to promote the narrative that more **dispatchable** fossil generation is needed and that the growing shift to renewables is undermining and driving up the cost of secure supply.

It is therefore important that advocates for a clean energy transition can set the record straight quickly, credibly, and substantively. This package is designed to equip them with information and tools to respond quickly to the misinformation that spreads rapidly in the wake of power grid reliability events.

We analysed the details of four significant outage events in grids with comparatively high shares of variable renewable generation – the Texas 2021 and California 2020 events in the United States, Great Britain's 2019 outage, and South Australia's 2016 grid event – which are included as case studies. We also reviewed how South Australia has successfully adapted its system operations to accommodate a predominantly renewable supply, demonstrating that such a system can be reliable as well as affordable.

Two of the events – South Australia and Texas – drew global news headlines, while for the other two – Britain and California – attention was predominantly national. In all four cases, the fossil-fuel industry was quick to point the finger at renewable energy. With the benefit of time and actual data, we pinpoint the true causes of the outages. Equipped with this information, we draw the following conclusions:

- Over the past decade, which was an era of rapid growth of renewable energy generation, not a single major outage was caused by over-reliance on renewable energy

or a shortfall of investment in dispatchable generation capacity. Each was caused by failures in the transmission or fuel supply systems, fossil generation failures, or a grid operating either while poorly regulated or under outdated standards.

- A grid with significant renewable generation can be just as reliable as any other grid. A responsible and effective grid operator can operate a high-renewables system reliably using well-understood and widely available tools.
- Energy industry regulators can help or hinder the transition to modern grid operation. In their oversight capacity, regulators can require these updated modes of operation and best practices.
- Dispatchable does not mean 'always available.' As demonstrated by the real-world case studies we review, dispatchable fossil and nuclear plants are not always available when needed, leading to outages. **System operators** have always faced the challenge of planning around the likelihood of generation being unavailable when it's most needed. Reliability is a system attribute and is not dependent on any specific class of resources.
- The variability of renewable energy is well understood. While batteries can help to re-shape supply to meet demand, there is vast potential to shape demand directly to match the availability of supply at a small fraction of the cost of batteries or of building seldom-used fossil generation infrastructure. Flexible demand can reduce the cost of reliability for all consumers.

These conclusions are a useful starting point for those combatting misinformation, especially following a significant grid outage. In the critical hours during and immediately following an event, while the details are still coming to light, advocates and others on the ground can point to the precedents of past events.

Reliability is a system attribute and is not dependent on any specific class of resources.

This toolkit includes the following components:

- An overview of the causes of grid outages and the role of the system operator
- Four case studies of outages, including useful reports and references
- A checklist for unpacking the true causes of a reliability event
- A best practice case study, showing that well-run systems with large volumes of renewables can be managed by competent and well-resourced bodies
- A primer on reliability and **resilience**
- A glossary of useful terms and concepts (glossary terms are in bold in their first usage for easy identification)

Contents

Grid outages: Causes and consequences

Each grid outage or reliability event (see Annex I for discussion of reliability) has its own peculiarities, but it will have as its root cause at least one of the following:

- Grid (also referred to as network) failure: for example, from a lightning strike or trees falling on transmission or distribution wires.
- Generation failure: for example, from a mechanical fault or upstream fuel interruptions affecting power plants.
- Unforeseen demand patterns: for example, from a historically rare spell of extreme weather (cold or heat) that drives up demand for power.

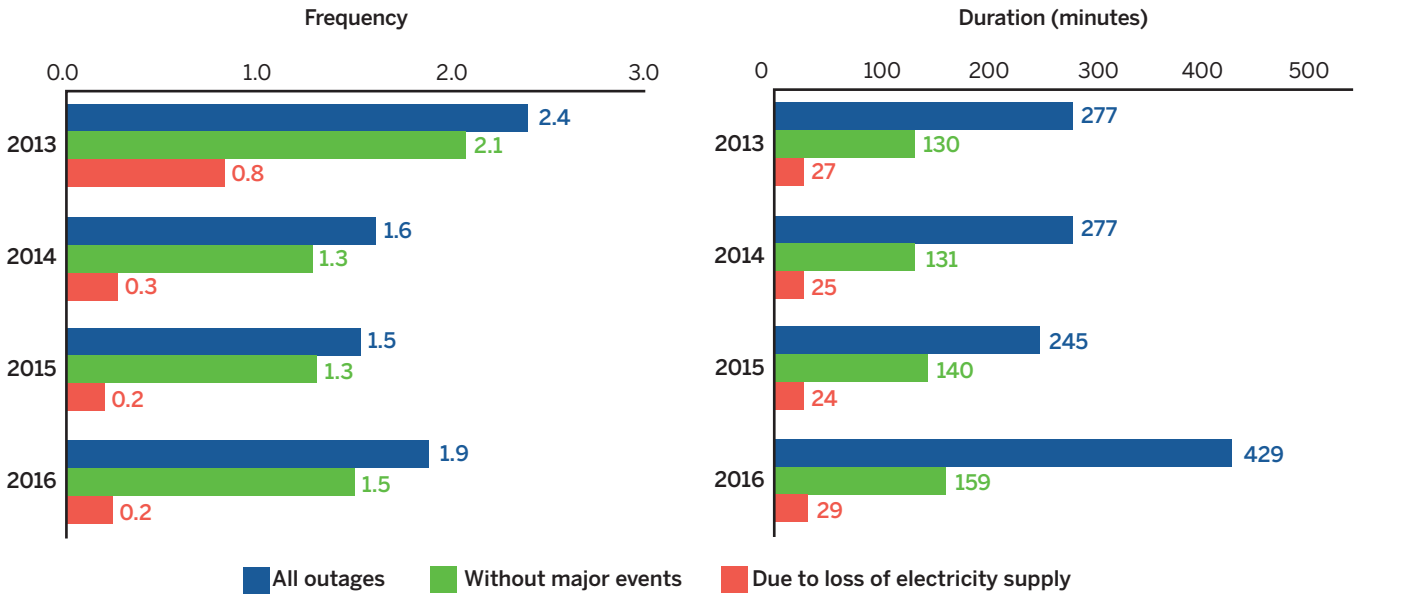
The overwhelming majority of service interruptions are not a result of loss of supply, but rather are traceable to networks (this is reflected in the difference between 'all outages' in blue and 'due to loss of electricity supply' in red in Figure 1).[1]

System operator's role in preventing outages

It is the job of a system operator – the designated 'traffic cop' of the electricity highway – to ensure that demand and supply are balanced at every moment. The grid operates on **alternating current** (a current that periodically reverses direction and changes its magnitude continuously with time). Most things connected to the grid are designed based on an assumption about how frequently the current will alternate (the **system frequency**), with very limited tolerance for deviations.

If for some reason supply unexpectedly falls below demand (for instance, a large power plant or transmission line fails unexpectedly) the system frequency begins to slow down.[2]

Figure 1. U.S. average customer electric outages, 2013-2016



Source: Larsen, J. et al. (2017, October). *Electric System Reliability: No Clear Link to Coal and Nuclear.* Rhodium Group.
Note: 'Frequency' depicted in occurrences per customer per year.

1 A study of U.S. data between 2013 and 2016 by Rhodium Group, for example, found that less than 1% of all customer hours of interruption were attributable to the inability to generate enough electricity. Larsen, J., Houser, T., & Marsters, P. (2017, October). Electric System Reliability: *No Clear Link to Coal and Nuclear.* Rhodium Group. https://rhg.com/research/electric-system-reliability-no-clear-link-to-coal-and-nuclear/

2 Conversely, if supply exceeds demand the system frequency speeds up; however, this situation can be remediated simply by reducing supply.

The system operator responds to this situation first by tapping into resources kept in reserve for this purpose. If that fails, the system operator can order sequential involuntary interruptions to groups of customers for limited periods of time, while protecting designated critical loads (consumption), such as those at hospitals. This is what is often referred to as **rolling or rotating firm service interruptions**, during which the grid remains operational.

If despite these actions the drop in frequency continues (for instance, due to additional failures triggered by the initial event) to the point that it exceeds that very tight band around the expected frequency, the system operator must begin shutting down the grid to avoid damaging power plant equipment, industrial machines and consumer appliances. In this case, the bulk power grid is no longer operational, the affected region of the system is dark, and in the worst scenarios it can take many days or even weeks to re-energise the grid. While there are usually stark differences in both cause and consequence between these two types of events – a rotating sequence of controlled interruptions vs. a total grid collapse – it is common for both to be labelled indiscriminately as blackouts.

How the system operator prepares for such circumstances depends on how much time they have to respond. Historically, system operators relied on the fact that large, heavy machines at power plants and industrial plants, rotating synchronously with the frequency of the alternating current, give the system a certain amount of in-built **inertia**, mechanically slowing the rate of decline in system frequency. As wind and solar increasingly displace fossil power plants,[3] there is less of this intrinsic source of resistance, potentially shortening the time the system operator has to respond to upsets in the system.

This need not present a threat to system reliability however: mechanical inertia in traditional fossil-based generators is not the only way to arrest a drop in system frequency; it is simply one that was historically abundant. There are a number of feasible alternatives, with more under development, and system operators are successfully adapting as situations evolve.[4]

System operators, regulators and energy ministries are also introducing reforms to unlock responsiveness of demand to align better with variable renewable supply. These reforms seek to support system **flexibility** through prices that clearly signal relative shortage of supply to demand, that stimulate helpful responses by consumers, and that help the system operator steer clear of the risk of rolling service interruptions in the first place.[5]

Bottom line: The differences in built-in inertia between fossil fuel power plants and wind and solar installations are not an impediment to reliably increasing the role for renewables. There are a number of feasible alternatives with more under development.[6] System operators, such as the Australian Energy Market Operator (AEMO), are successfully adapting their operating practices to accommodate increasing amounts of renewable energy on their systems (see best practice case study), pointing to a future when lower mechanical inertia will not be a pressing concern. In any case, a focus on unlocking system flexibility helps the system operator steer clear of rolling blackout risks in the first place.

Consequences of different types of outages

At an individual customer level, the loss of electricity is problematic regardless of what caused it or how widespread it might be – but from a societal perspective, the nature of the event can matter a great deal. Table 1 provides an illustrative survey of the range of consequences different reliability events can have.

Local, distribution-level events are the cause of the great majority of interruption hours for customers. The growth of distributed renewable generation presents new challenges for system operators overseeing the distribution networks, but with prudent regulation there is no reason they should lead to

3 Wind generators are rotating machines, but they rotate at a much lower frequency; as a result, they're not 'synchronized' to the grid and do not offer this intrinsic mechanical inertia.

4 Denholm, P., Mai, T., Kenyon, R., Kroposki, B., & O'Malley, M. (2020, May). *Inertia and the Power Grid: A Guide Without the Spin.* National Renewable Energy Laboratory. NREL/TP-6120-73856. https://www.nrel.gov/docs/fy20osti/73856.pdf.

5 Yule-Bennet, S. & Sunderland, L. (2022, June). *The joy of flex: Embracing household demand-side flexibility as a power system resource for Europe.* Regulatory Assistance Project. https://www.raponline.org/knowledge-center/joy-flex-embracing-household-demand-side-flexibility-power-system-resource-europe/

6 For example, recent pilots in the UK to use wind turbines for inertia. Davies, R. (2022, March 7). Onward inertia! The secret source for keeping the lights on and greening the grid. *The Guardian.* https://www.theguardian.com/business/2022/mar/07/onward-inertia-the-secret-source-for-keeping-the-lights-on-and-greening-the-grid

Table 1. Typical consequences of reliability events (traffic light, with red most severe impact)

	Local distribution failure	Rolling interruption (well managed)	Rolling interruption (poorly managed)	Blackout
Inconvenience	🔴	🔴	🔴	🔴
Loss of welfare	🟠	🟠	🔴	🔴
Threat to public health	🟢	🟢	🟠	🔴
Threat to public safety	🟢	🟢	🟠	🔴
Loss of essential services	🟢	🟢	🟠	🔴
Price spikes	🟢	🔴	🔴	🟢

Source: RAP graphic

more frequent interruptions.

Although these events tend to attract little media attention and are therefore not the target of this exercise, they do establish the individual consumer's baseline experience of reliability against which other, less common types of events must be considered. The focus, however, of this toolkit is the events that attract broad, high-volume attention (and misinformation campaigns): rotating interruptions and blackouts, resulting from problems in the bulk or wholesale power grid.

Rotating interruptions are an intentional (if very sparingly used) tool in a prudent system operator's planning toolbox for maintaining system stability. This reflects the fact that it is technically unrealistic and economically undesirable to plan to never have a shortfall of supply. This is due to the exorbitant additional cost of attempting to increase system supply source reliability beyond, say, 99.97%. If rotating interruptions remain rare and are well-managed enough to stabilise system frequency and prevent system-wide collapse, they can have minimal social costs beyond those associated with local distribution failures. If they're poorly managed, however, the consequences are magnified and social costs can be high (e.g. Texas 2021).

The consequences of true blackouts (i.e. total grid collapse) are dire, and the cause is invariably an extraordinary event (such as Hurricane Ida) or a rapid sequence of otherwise ordinary events (such as the cascading transmission and generator failures that caused the 2003 Northeastern U.S. blackout) that overwhelm the system operator's ability to arrest the decline in frequency. The root cause of true blackouts is almost always a major transmission system failure.[7] With competent operation, planning and regulation, there is no reason to expect that an increase in variable renewables should increase the likelihood of such events.

Bottom line: Large-scale events like those described in the case studies below are almost always caused by failures at the transmission system level (with a recent increase in incidents traced to problems with upstream natural gas supply and/or infrastructure). There is no reason for the growth in renewables to change this, not least given the efforts of system operators and regulators to address challenges associated with the energy transition. This includes addressing potential shortages of inertia by unlocking innovative new sources of frequency response services; and it includes efforts by regulators to unlock system flexibility, such as with smart tariffs, that empower consumers to contribute to maintaining reliability at low cost, for instance by charging their electric vehicle in a manner that supports grid security.[8]

7 Power Technology. (2015, January; 2020, June update). *The 10 worst blackouts of the last 50 years.* https://www.power-technology.com/features/featurethe-10-worst-blackouts-in-the-last-50-years-4486990/

8 Hildermeier, J., Kolokathis, C., Rosenow, J., Hogan, M., Wiese, C. & Jahn, A. (2019, April). *Start with smart: Promising practices for integrating electric vehicles into the grid.* Regulatory Assistance Project. j

The checklist

The checklist supports identification of the true causes of a reliability event. It considers the event background, root driver, the plan for dealing with such eventualities, and how plans were inadequate. This checklist provides a framework that can be used to debunk the claims of parties seeking to blame renewables for reliability events.

The best sources for timely information to answer checklist questions are typically the system operator, the energy regulator, and the organisation administering energy markets. It may however take time for them to provide detailed reporting.

Before the facts are established, advocates of the clean energy transition have the opportunity to caution that any narrative blaming renewables for events is premature and nearly always turns out to be misinformation. They can also prevent others with business or political interests from seizing the narrative.

The checklist:

a. Demand and supply – what was the background?

- ❑ Was demand high, normal, or low?

b. What appears to be the root cause(s) based on best available information?

- ❑ Grid failure, generation failure, or unforeseen demand patterns?

c. What was the relative severity of the event?

- ❑ How many consumers were affected, for how long, with what specific consequences?

d. What was the system operator's resource plan for meeting demand under the relevant circumstances (assuming there was one)?

- ❑ How much operational capacity did it expect to have in reserve?

e. What was the expected role for renewables in the relevant contingency plan?

- ❑ How many gigawatts of wind and solar and other renewables was the system operator banking on being in operation under the circumstances?

f. To what extent did the system operator plan for and deploy demand flexibility?

- ❑ Did the system operator have access to voluntary curtailment by large industrial consumers for compensation?
- ❑ Are dynamic retail tariffs and smart technology widely deployed across the system?

g. How exactly did the plan fail, i.e. what was supposed to have happened that did not (not what renewables didn't do that they weren't expected to do)?

- ❑ Compared to the system operator plan, how much fossil fuel plant failed to materialise?
- ❑ Compared to the system operator plan, how much renewable energy failed to materialise?
- ❑ Was the level or shape demand caused by circumstances that couldn't reasonably be anticipated given historical experience? Or was there a failure to adequately plan for circumstances that should have been anticipated?

h. What false claims are being promoted by fossil industry players and their enablers?

- ❑ What are they reporting in the media?

i. Why exactly are the claims false?

- ❑ How do the claims stack against the root cause (b) and details of the plan failure (g)?

j. Are there legitimate transition-related challenges manifested in the event?

- ❑ Was a shortage of system inertia an issue?
- ❑ Was production from the wind and/or solar fleet below the reasonably expected range under the circumstances?

k. What best practices could a prudent system operator have employed to avoid the event?

- ❑ Were protections from changes in system frequency set appropriately in plants (and not overly sensitively), and was compliance enforced?
- ❑ Did the system operator have oversight of generation on the distribution network system?
- ❑ Did the system operator procure sufficient system inertia (or inertia replacement services)?

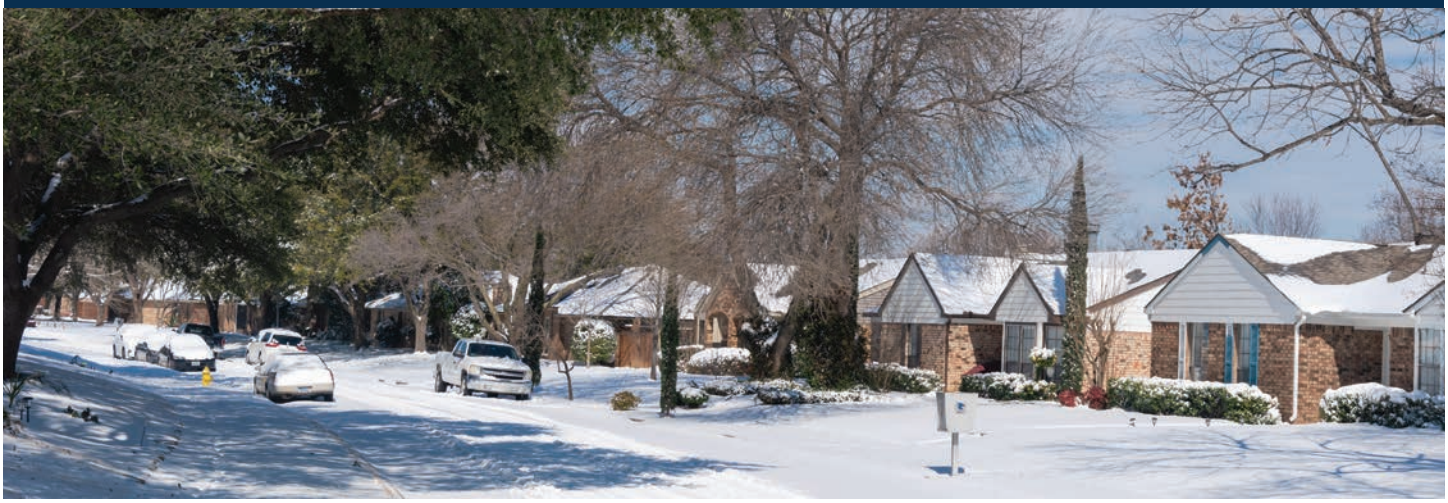
One of the case studies in this toolkit – of the February 2021 event in Texas – draws on the checklist to illustrate how it can be employed to unpack events in practice. You can find that checklist on Page 28.

Four case studies

To build this toolkit, we examined four significant grid outages that drew global attention: Texas 2021, California 2020, Great Britain 2019 and South Australia 2016. For all these high-profile case studies, we can show that renewables were not the primary cause.

Adobe stock vector illustration

Texas 2021



Adobe stock photo of the 2/2021 Texas winter storm

Overview

This February 2021 event was caused by a winter storm of historic depth and duration – rare but not unprecedented for Texas. More than 4.5 million customers lost power, many for three or more days. The severe conditions, in a region heavily reliant on resistance electric heat in poorly insulated buildings, led to as many as 200 deaths and billions of dollars in property damage.

Demand and supply situation

The cold weather drove demand to unforeseen levels. Some amount of rolling interruption over a few hours would likely have been necessary in the best-case scenario. Demand at the onset of the winter storm was above the extreme winter contingency level, more typical of Texas's demanding and very hot summer conditions. Demand peaked during the event at the highest level on record up to that time.

Supply was initially scarce but sufficient to meet the record demand. Within hours, however, nearly 50% of planned generation failed – mainly gas-fired, but also 40% of coal and one of four nuclear units. The plant failures were caused by a combination of inadequate freeze protection at the plants themselves and in the fuel supply infrastructure on which they rely. Regional gas production fell by about 50% before beginning to recover. This was all largely unforeseen.

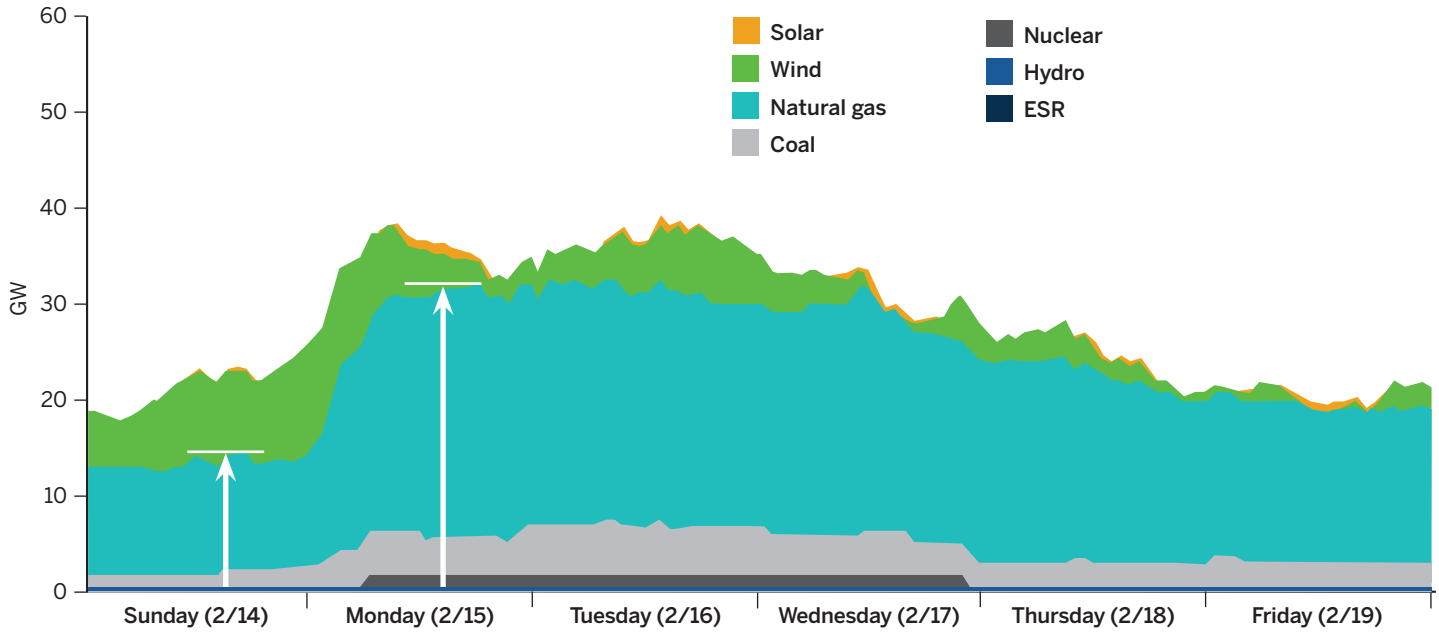
Wind power typically supplies over 20% of Texas's *annual* electricity. Over half of the wind fleet was out of service, but the system operator plans on only about 20% of potential wind production (about 7 GW) under severe winter conditions. In the event, the fleet operated at a bit more than 10% of potential (about 4 GW, or 57% of plan in severe winter conditions) on average.[9]

This points to a very minor failure of wind, and a colossal failure of gas and coal plants. Figure 2, which plots outages of generation plant by technology, shows that the widespread service interruptions that began early in the morning of 15 February were stimulated first and foremost by a steep rise in fossil plant outages, especially in natural gas plants.[10] These account for nearly the entire reduction in lost energy output that day, along with coal and nuclear failure, the vast majority of which the system operator would have been counting on. It shows that the role of lost wind output on the day was relatively modest, being not significantly higher than on the previous day. It should also be noted that the system operator did not intend to use all this output in its emergency planning in the first place.

9 ERCOT's winter resource plan includes a 'low-wind' scenario of about 2 GW. That scenario, however, is not integrated into the 'extreme' winter system demand and supply scenario.

10 University of Texas at Austin Energy Institute. (2021, July). *The Timeline and Events of the February 2021 Texas Electric Grid Blackouts.* https://energy.utexas.edu/sites/default/files/UTAustin%20%282021%29%20EventsFebruary2021TexasBlackout%2020210714.pdf

Figure 2. Net generator outages by fuel type



Source: University of Texas at Austin Energy Institute. (2021, July). *The Timeline and Events of the February 2021 Texas Electric Grid Blackouts.*
Note: Figure was reused and cited from an ERCOT public presentation. The outsized role of non-variable renewables technologies – and especially natural gas – in the failure of generation capacity is illustrated by the difference in height of the white arrows between 14 and 15 February.

Unlike other regions of North America, Texas's grid is effectively an island electrically isolated from neighbouring systems for historical reasons. As a result, there is limited ability to mitigate events by broadening the supply solutions. That said, as the crisis affected a broad swathe of the midcontinent, it is unclear just how much help would have been available.

The plan and how it failed

Demand of more than 77 GW exceeded the system operator's extreme winter planning scenario of 67 GW.

Available resources at the onset of the storm were roughly in line with the winter planning scenario and were stretched to the limit to meet demand. About 90% of planned generation was fossil and nuclear, three-quarters of that being natural gas. Wind generation made up the bulk of the remaining planned resources.

While the system operator would likely have had to resort to some level of rolling interruptions for a few hours as the storm continued through the week, truly dire consequences would probably have been averted had the thermal generation fleet held up as planned.

This is illustrated in Figure 3 below.[11] It shows that the system operator, in its most extreme emergency scenario plan, planned for only about 10 GW of forced outages of generating plant based on historical experience (left-hand side). During the event, however, 26 GW of forced outages materialised (right-hand side).

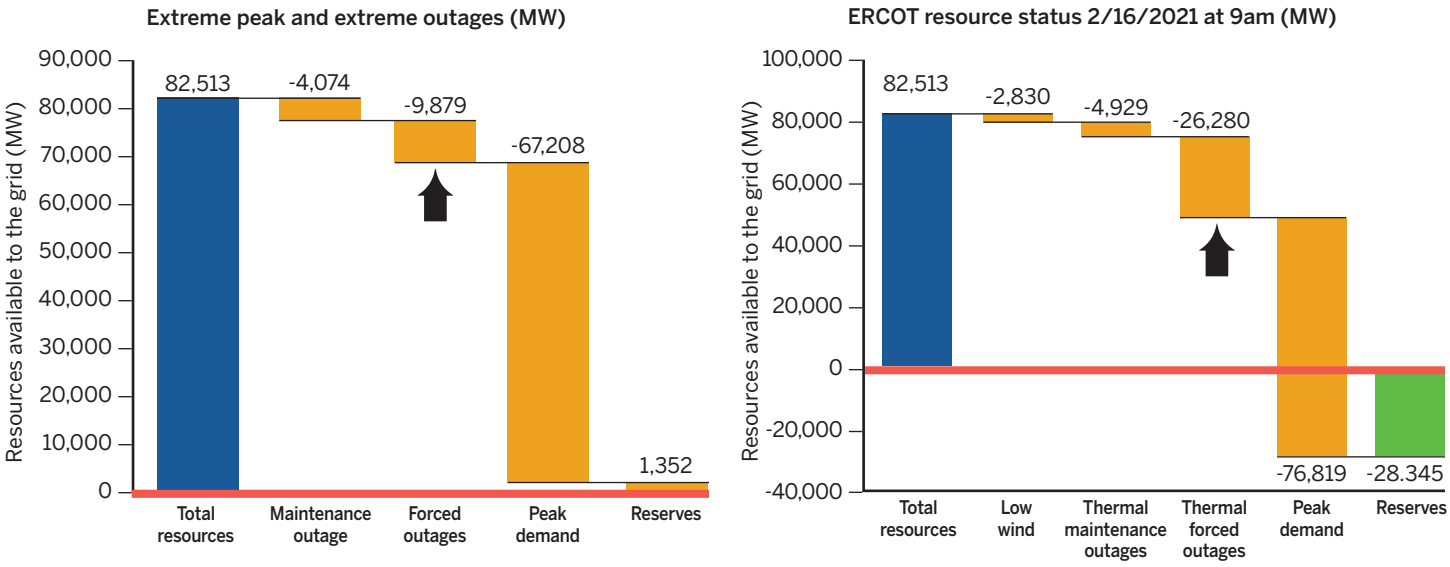
Thermal generation (that was reasonably expected to operate) failed, largely because of its reliance on natural gas infrastructure that was far more vulnerable to severe winter weather than either the system operator or the regulator anticipated. Equipment freeze-ups at the plants themselves were also a major issue. Most of the wind fleet was also frozen – that's an issue for the future, but it was also largely expected and accounted for in plans.

Dispelling the myths

Fossil industry actors, including the state's natural gas regulator, were quick to point to Texas's rapid uptake of wind over the past 20 years and the large amount of wind generation

11 University of Texas at Austin Energy Institute, 2021.

Figure 3. The Texas scenario (left chart) and the actual event (right chart)



Source: University of Texas at Austin Energy Institute. (2021, July). *The Timeline and Events of the February 2021 Texas Electric Grid Blackouts.*
Note: Figures come from public data from ERCOT.

(about 18 GW of the 32 GW installed) that was offline at the time. The narrative bounced between the Texas wind fleet's vulnerability to freezing and the effect of low wind speeds during cold winter weather on the 'dispatchability' of wind.

The fact that the system operator's plan accounted for both of these factors, and that they therefore had little to do with why the disaster occurred, went conveniently unmentioned. The claims are a familiar mix of factual snippets removed from context, woven into an intentional misrepresentation.

Lessons

The fact that the system operator's plan to deal with these circumstances continues to be so heavily reliant on fossil fuels is a concern, as is the fact that the Texas renewables resource is so reliably unreliable under these circumstances. Both challenges call for known solutions, including on the demand side.

The following best practice could help to avoid this type of event in future:

- As extreme weather events become more common and severe due to climate change, regulators and system operators will need to update their scenario planning based on the trends evident in more recent historical information, including this event.
- There should be stronger oversight and 'no excuses' enforcement of operational standards for critical resources, including the upstream infrastructure on which they rely.
- Aggressive deployment of end-use efficiency measures, such as heat pumps to replace electric resistance heat and improvements in building insulation, is required to increase demand flexibility, reduce overall demand, and safeguard public health.
- There is a need for implementation of smart distribution-level technologies and smart pricing to adequately incentivise shiftable loads to be shifted away from peak hours without unduly inconveniencing end-use customers.
- The distribution system should be better sectionalised to allow more targeted control over what demand gets protected (e.g. critical infrastructure) and what is available for rotating interruption.
- The Texas grid's linkages with neighbouring systems should be increased to expand options for dampening the impacts of future such events.

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California 2020

Adobe stock photo of California wildfire

Overview

From 14-19 August 2020, western North America – extending from northern Mexico to British Columbia, and from the desert interior to the Pacific Coast – experienced a severe and extended heat event of historic dimensions. This occurred during a summer that overall had been hotter and drier than normal across the West. Much of the attention around this time was on the recurrence of what have become increasingly frequent and intense wildfires. The causes of some of the highest-profile and most catastrophic wildfires in recent years have been traced to downed high-voltage transmission infrastructure. To reduce risks to life and property and the associated financial liabilities, some of the utilities that own the region's transmission facilities have begun pre-emptively de-energising transmission facilities under certain conditions, at times blacking out large areas in the region for days or even weeks at a time. Mid- to late-August 2020 saw an especially dangerous convergence of these factors, with large wildfires burning out of control along the West Coast, extreme heat and drought conditions even in the normally cool, damp Pacific Northwest, and higher-than-normal, unusually round-the-clock air conditioning and refrigeration loads, especially in the Desert Southwest region.

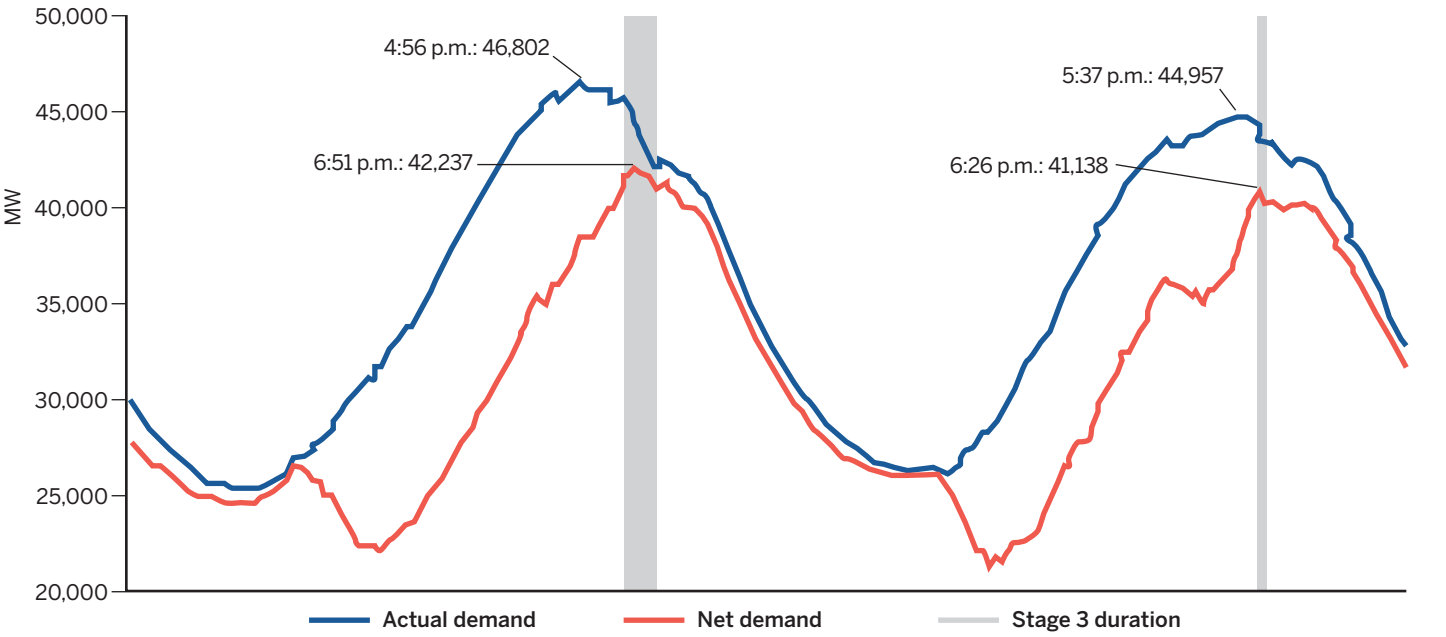
It was against this backdrop that, in the early evenings of 14 and 15 August, the California Independent System Operator (CAISO) was forced to order distribution utilities in its footprint to initiate a series of controlled firm load curtailments, cutting service to rotating groups of customers over a one-hour period on 14 August and a 20-minute period on 15 August, in order to preserve the minimum level of contingency reserves required to insure that a major unplanned event (such as the failure of a major transmission line or the shutdown of the system's largest power generator) would not lead to a catastrophic system failure across CAISO and beyond. The load sheds ordered by CAISO were for 500 MW on both days, or approximately 1.1% of actual firm demand in each case.[12]

Demand and supply

The extreme heat event that began on 14 August and carried on until 19 August amounted to a 1-in-30-year meteorological event in California, based on historical data for intensity and duration. There is little precedent for similarly extreme weather conditions simultaneously affecting regions to the north, south and east of California. Yet while actual peak demand across the entire region on both days exceeded forecasted peaks, in CAISO's control area voluntary demand response and activation of interruptible loads played a critical

12 Pacific Gas & Electric customers experienced interruptions of up to 150 minutes on 14 August and up to 90 minutes on 15 August due to logistical issues, and for the same reason actual demand shed was slightly higher on both days.

Figure 4. CAISO demand and net demand for 14 and 15 August



Source: CAISO. (2021, January). *Final Root Cause Analysis, Mid-August Heat Wave.* Note: Licensed with permission from the California ISO. Any statements, conclusions, summaries or other commentaries expressed herein do not reflect the opinions or endorsement of the California ISO.

role in reducing actual peak demand. As a result, peak demand for energy exceeded forecasted peak by only 4.6% on 14 August and by a mere 0.5% on 15 August.[13] In fact, peak demand was higher later in the week as the cumulative effects of the multi-day heat event intensified, yet no firm load shed was required. (It's also worth noting peak demand was well below CAISO's then-historic peak demand of 50.1 GW,[14] which occurred in 2017 and was 7% higher than the 14 August peak of 46.8 GW.)[15] More to the point, the order to shed firm load occurred not when demand peaked, but nearly two hours later on 14 August and nearly one hour later on 15 August, when *net demand* peaked. Net demand is the residual load to be met by more expensive non-variable resources once the load covered by low marginal cost variable resources like wind, solar and run-of-river hydro (principally solar) is netted out. This net load profile is the result of the normal pattern of variable production – with solar production ramping down late in the day – that is well understood and is factored into CAISO's resource planning. Like peak gross demand, peak net demand was also higher later in the week, as shown in Figure 4, yet no load shed was required.[16]

Taken together, this illustrates that the shedding of firm load on these two days was not driven by demand that was dramatically in excess of forecast, or by a shortage of investment in generation resources, or by an unanticipated problem with variable resources. As CAISO CEO Steve Berberich said after the event, 'What caused the [firm load shed] was a lack of putting all the pieces together… You have to rethink these old ways of doing things, and I think that's what didn't happen.'[17]

13 CAISO. (2021, January). *Final Root Cause Analysis, Mid-August 2020 Extreme Heat Wave.* Figure 4.2. http://www.caiso.com/Documents/Final-Root-Cause-Analysis-Mid-August-2020-Extreme-Heat-Wave.pdf

14 CAISO. (2022). *California ISO Peak Load History 1998 through 2022.* https://www.caiso.com/documents/californiaisopeakloadhistory.pdf

15 CAISO, 2021.

16 CAISO, 2021.

17 Hering, G. & Stanfield, J. (2020, September 25). 'You have to rethink these old ways': Parting advice from CAISO's retiring CEO. *S&P Global Market Intelligence.* https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/you-have-to-rethink-these-old-ways-parting-advice-from-caiso-s-retiring-ceo-60481529

The plan and how it failed

CAISO's resource planning process is more complex than in many regions. In addition to the rapid growth in wind and solar production (with much of the solar behind the meter), the native resource portfolio includes a large amount of hydroelectric generation with limited reservoir storage capacity. The system is also heavily interdependent with neighbouring regions connected over long distances by high-voltage direct current transmission lines. Resource plans in each region are reliant on large amounts of power flowing in one direction under certain conditions (e.g. daytime vs. night-time, or summer vs. winter) and in the opposite direction under the obverse conditions. As already noted, even given the severe operating conditions that prevailed on these and the following days, the supply of resources was sufficient to meet peak demand for energy and the planned level of system reserves. The order to shed firm load occurred only later as demand was beginning to ramp down. Solar production was also ramping down and CAISO was attempting to ramp other resources up (or dispatch more demand response) to meet demand and maintain the required level of contingency reserves. While this is a daily challenge that CAISO manages regularly and managed successfully later in the week under comparable circumstances, on these two days its efforts fell short.

Dispelling the myths

Why this occurred is complicated. While the operational challenge exists in part because of the known production characteristics of wind and solar – particularly solar – there was nothing especially unusual about production from either resource on those days. During the time of the net peak at that time of year, the planned contribution of solar and wind combined would have met about 10% of what was needed, or about 4,100 MW. Solar production on 14 August – the more challenging of the two days – was near normal for that time of year, while production was lower on 15 August due to cloud cover in the north; production on both days was affected by smoke from wildfires. Solar production during the net demand peak fell short of the resource plan by about 1 GW on both days. Wind production was somewhat lower than normal and below the resource plan by 640 MW on 14 August and 230 MW on 15 August.[18] These lower wind and solar production levels, while unfortunate under the circumstances, both fall within the level of variability around which CAISO would normally manage successfully.

Customary operating challenges were certainly exacerbated by the challenging weather conditions, but the overall resource situation was adequate – due, for instance, to the fact that despite a 900 MW derating of one of the major import lines from the north, imports performed well above expectations. In the end, the inability to meet net peak demand on these two days was the result of a combination of factors that compromised CAISO's ability to fully respond to the usual evening ramps. Nearly 10% of the natural gas generation fleet, about 60% of what was expected to meet the ramp up of demand to peak, and normally a reliable source of flexibility for following the evening ramp, was on a forced outage. And due to a complicated set of circumstances, both CAISO and the retail suppliers had significantly under-scheduled day-ahead demand, meaning resources that normally would have been online and able to follow the evening ramp were not committed in time to do so. As the CAISO CEO said, '…a lack of putting all the pieces together.'[19]

Lessons

The causes of the event were multiple and complex, as is usually the case. While the variability of renewables figured in the chain of events, this had been well understood and planned for. Wind and solar both delivered less than had been scheduled, but the difference was within a normal range of uncertainty. There were a number of components of the plan to accommodate that variability and uncertainty in a reliable grid that, on those two days, failed.

18 CAISO, 2021.

19 Hering & Stanfield, 2020.

Some of the failures were of a conventional nature, such as a higher-than-normal number of forced thermal plant outages – this was unfortunate and was perhaps exacerbated by the extreme weather, but it's the sort of thing for which contingency reserves are retained. Harder to justify were the decision to allow planned thermal plant outages in the middle of an unusually difficult summer peak season, or the miscommunications that led to the failure to commit available flexible generation online in advance of the evening ramp. Finally, there were the failures in adapting the planning process itself in ways that would ensure the system remains reliable as it transitions. This included a failure to incorporate what are likely to be more frequent and more extreme weather events into the planning process to account for their impacts on both demand and on supply. It also included the need to update resource planning tools to account for the fact that resource adequacy can no longer be measured (to the extent it ever could be) by the amount of capacity available during a few peak demand hours. While demand flexibility played a crucial role in limiting the scale of this incident, there is broad agreement that it has much more potential, and that the planning process needs to play a more active role in empowering consumers to take more control over how much electricity they need and when they need it.

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Britain 2019

stocker1970/Shutterstock

Overview

The events of 9 August 2019 were triggered by a lightning strike on a transmission line. This led to loss of large wind and gas generation resources, as well as small-scale solar and small diesel engines connected to the distribution system (**embedded generation**). This loss of generation exceeded the loss the system operator was prepared for. As a result, roughly 1 million customers lost power for around 15 to 45 minutes. The event points to the importance of proper regulation to provide plant oversight, especially of embedded generation, and to ensure they are not overly sensitive to changes in system frequency.

Demand and supply

On 9 August 2019, wind provided 30% of energy, gas 30%, nuclear 20%, interconnectors 10%, and embedded generation – generation on the distribution network – contributed the remaining 10%. Demand was reported as not unusually high.

A lightning strike quickly led to the sustained loss of generation output from a wind farm, a gas-fired power plant and multiple small, embedded generators – solar, wind and some reciprocating engines (fuelled by diesel or gas).

The plan and how it failed

It was a windy day with low demand, and as such there was low inertia on the system – requiring additional measures to manage sudden changes in system frequency. Nonetheless, the system operator had ensured adequate levels of inertia to cover the largest expected loss of energy onto the grid on the day, and was therefore delivering on its plan.

The wind plant that failed in response to the effect of the lightning strike on the network was not yet fully commissioned and was under a temporary plant protection scheme. This allowed the plant to turn off in response to changes in grid frequency to protect itself. The system operator was unaware of this arrangement. The unexpected contribution of the wind plant to the event thus stems from an absence of oversight and proper regulation, unrelated to the variable nature of this renewable resource.

Why the gas plant failed is less clear.[20] Nevertheless, it appears to have contributed as much to the supply failure as did the loss of the wind plant.

20 For instance, RWE confirmed that for 'reasons presently unknown, after approximately 1 minute the first gas turbine tripped due to a high-pressure excursion in the steam bypass system.' See: National Grid. (2019, September). *Technical Report on the events of 9 August 2019*. https://www.nationalgrideso.com/document/152346/download

The rapid-fire and apparently unrelated failure of these two plants triggered further perturbations in system frequency. Embedded generation subsequently tripped offline in response due to its own overly sensitive protection schemes. The combined generation outages exceeded the contingency scenario underlying the system operator's resource plan. This pushed the system past its limits.

Thus, the failure in planning appears to link first with the failure to address unnecessarily sensitive energy generation under-frequency protection schemes. This was compounded by a lack of system operator oversight of embedded generation, and an inadequate supply of inertia services to mitigate the impact of the combined events.

Dispelling myths

One day after the blackout the Daily Mail reported 'experts blame the UK's over-reliance on wind energy for the worst power cut in years.'[21]


Mail Online

Revealed: Britain was hit by TWO blackout 'scares' in the last three months as experts blame the UK's over-reliance on wind energy for the worst power cut in years — but boss of National Grid claims 'the system worked really well'

It is disingenuous, to say the least, to blame the event on renewables.

While the tripping-off of a wind farm on under-frequency protection contributed to the event, that failure was not related to the fact that it was a wind farm, but rather to the combination of unfortunate timing and a failure to notify the system operator appropriately. It is noteworthy that several other offshore wind farms, electrically closer to the initial fault, were unaffected.

If reliance on variable generation played a role, it was the reliance on embedded solar, not wind, and again the failure was unrelated to the variability of the resource. It was instead caused by a lack of information and the incomplete implementation of new rules to ensure this embedded generation supports, rather than detracts, from system reliability. In other words, it was unfortunate that the event occurred before the changes in the grid code could be fully implemented. Note that embedded generation included both diesel engines and renewables, and the variability of the latter was not identified as a driver of the event.

Lessons

The first lesson is that smart regulation is necessary to ensure that plant, including embedded generation, is not needlessly sensitive to changes in frequency. The system operator had initiated a programme of upgrading the under-frequency settings of embedded solar generation, but the project was still several years away from completion. A plant that is operating, but formally still in commissioning stage, should be notified to the system operator, and this need is not specific to the type of generation.

Second, greater oversight of embedded generation is required. Indeed, a register of embedded generation capacity above a particular threshold was approved by the regulator in 2020.[22]

Third, and for the longer term, the underlying philosophy of shutting down all embedded generation on loss of grid power until the grid is restored needs replacing with something more appropriate for the future. Strategic deployment of (grid-forming inverter) technology on some share of embedded generation to allow for local islanding should be considered.

Finally, the system operator ensured adequate levels of inertia to cover the largest expected loss of energy supply onto the grid on the day, and its final report suggests that its actions before and during the events were in accordance with

21 Bucks, J. (2019, 10 August). Revealed: Britain was hit by TWO blackout 'scares' in the last three months. *The Mail on Sunday.* https://www.dailymail.co.uk/news/article-7344969/Experts-blame-UKs-reliance-wind-energy-worst-power-cut-years.html

22 Ofgem. (2020, July). *DCP350 – Creation of Embedded Capacity Registers: Decision.* https://www.ofgem.gov.uk/publications/dcp350-creation-embedded-capacity-registers

industry requirements. It is appropriate, however, to revisit the arrangements – the formulation of system operator plans – for maintaining the resilience of the system during extreme events as the energy mix changes. A focus on procuring sufficient system inertia and inertia replacement options is necessary in the face of growing renewables, and the system operator has reinvigorated its focus on this in the interim.

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South Australia 2016

Adobe stock photo

Overview

In South Australia in September 2016, a once-in-50-years storm, including two tornadoes and an estimated 80,000 lightning strikes, knocked out 22 high-voltage pylons. This kicked off a dramatic drop in system frequency, which in turn prompted generating plants (nine wind farms) to stop exporting energy to the grid due to technical settings that triggered automatic protection mechanisms and disconnection more readily than desirable with voltage disturbances. This led to increased strain on an interconnector (a high-voltage wire importing electricity) from Victoria, which tripped as well, exacerbating the demand-supply imbalance. Ultimately the system operator was forced to disconnect from the National Electricity Market and almost everyone in South Australia lost power. Around 1.7 million people were affected, and for the majority it lasted about 6 hours. The event itself was not caused by an increased reliance on variable renewable generation, instead it focused attention on a range of emerging challenges the system operator confronted in ensuring security of supply at a time when the resource portfolio was undergoing a rapid transformation. Although some disruption owing to the exceptional weather conditions may have been inevitable, the episode nevertheless points to the importance of proper regulation and compliance to ensure appropriate technical settings on generation kit.

Demand and supply

In the period immediately before the event in September 2016 the South Australia system, which has a peak gross demand of approximately 3 GW, derived approximately 70% of its energy from wind and solar. An interconnector was importing from Victoria. Demand is not reported as having been exceptional.

The plan and how it failed

In the event of plant failure, the system operator planned to call on voluntary contracts with large industrial consumers to interrupt their supply, and to import more energy through the interconnector. The plan fell apart, however, in a lack of information about the potential extent of generation failure in response to a series of frequency perturbations, such as those caused by the loss of multiple major transmission facilities. This was due to the failure by the owners of several of the wind farms employing technology from a specific vendor, or by the vendor themselves, to inform the system operator that the turbines were installed with overly conservative under-frequency protective settings.

This was exacerbated by regulatory rules prohibiting the system operator from incurring additional costs to provision the system with increased inertia (by reducing wind output and starting up large thermal plants) in advance of the threat of unusually severe weather.

Dispelling myths

The day after South Australia lost power, Australian Deputy Prime Minister Barnaby Joyce focused attention on the possibility that the event reflected enhanced vulnerabilities stemming from the nature of renewable energy, stating 'obviously we know that South Australia has had a strong desire to become basically all renewable energy and the question has to be asked does this make them more vulnerable.'[23] And some linked the blackout to the closure of a South Australian coal power station in May that year, cutting coal out of South Australia's electricity production equation for the first time.[24]


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SA blackout: Nick Xenophon, Barnaby Joyce blame renewables

Industry experts, however, suggest coal would have made no difference. Dylan McConnell, Research Fellow – Energy Systems, Climate & Energy College and Energy Transition Hub, said: 'If those coal-power stations were still operating, they still would have dropped offline and seen the cascading failure that tripped the generators. Having those thermal generations there wouldn't have helped at all.'[25]

The primary cause was a combination failure of certain turbine suppliers to notify the system operator of excessively conservative protective settings, compounded by outdated regulatory constraints – all triggered by an extremely severe weather event and the related, extraordinary failure of transmission infrastructure.

Even so, it may also be noted that Australia's grid is particularly vulnerable. The National Electricity Market is among the world's most spread-out interconnected electricity grids – so when there's a major failure on one line, there are far fewer alternative routes for the electricity to flow. This means power lines are particularly prone to overloading and tripping out, a scenario which is particularly the case in states such as South Australia. As such, some interruption may be expected during truly exceptional weather events.

Lessons

Regulatory reform is key to address the root of the failure, along with enforcement action to incentivise compliance, accompanied by planning to accommodate growing renewables.

In terms of enforcement, in the years that followed the blackout, the Australian Energy Regulator took a number of wind farm operators to court over excessively sensitive protection mechanisms. In the court proceedings, two operators acknowledged that they had not gained prior written approval before applying their particular low-voltage ride-through system settings to their generating units.

Regulatory changes have also since been implemented targeting unhelpful turbine settings: had these been in place at the time, the state-wide blackout would likely have been avoided.[26]

Plans to accommodate growing renewables include a new Australian Energy Market Commission (AEMC) rule that better identifies emerging risks to power system security. The rule changes the way market operators and network service providers assess the kind of risks that can lead to cascading outages or major supply disruptions in the power system, and requires providers to collaborate with AEMC to ensure the operator has the information it needs to conduct these risk reviews. At the same time, the system operator has focused attention on developing plans and new tools – such as the unlocking of green inertia sources – to support secure operation of the power with very high levels of renewables.

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Overview of lessons with examples of good and bad practice

There are common lessons running through each case study. Chief among them is the need for adequate planning to identify the practical challenges system operators face when it comes to ensuring security of supply as the resource portfolio undergoes rapid transformation towards renewable and distributed resources. Planning must take into account the potential for more extreme weather patterns as a result of climate change. Table 2 presents a summary.

Table 2. Lessons and examples of good and bad practice

	Pertinent case studies			
	Texas	California	Britain	Australia
Updating scenario plans for more extreme weather, drawing on trends evident in more recent available information				
Factoring into plans the impact on demand – for instance, Texas was an example of a failure to consider the impact of extreme cold on electricity demand as consumers turned on inefficient resistive electric heating	✔			
Factoring in to plans the impact of extreme weather on supply such as generation capacity and/or other critical infrastructure – for example, California illustrated a lack of preparation for the effect of extreme heat on thermal generation capacity	✔	✔		
Ensuring reliable sources of flexibility are available to accommodate growing renewables				
To meet needs within changing patterns of the renewables resource supply – for instance, by significantly increasing commercial arrangements with controllable demand and in development of price-responsive demand in South Australia		✔	✔	✔
By procuring sufficient system inertia and inertia replacement options as traditional sources are phased out – for instance, South Australia has since installed four synchronous condensers to increase system inertia without the need for additional thermal generation, and now has the world's first big battery to deliver grid-scale inertia services			✔	✔
Providing strong oversight and 'no excuses' enforcement of operational standards				
For critical resources including the upstream infrastructure on which they rely, including during extreme weather – this would have been particularly helpful in Texas in the case of gas conveying infrastructure, and it is not clear that the new penalties introduced are sufficient	✔			
To ensure that plants are not excessively sensitive to changes in frequency, including renewables, embedded generation, and plant operating but not fully commissioned – the British energy regulator for instance here launched a review, including protection settings on distributed generation to ensure appropriate regulations			✔	✔
Aided by greater oversight of embedded generation, including registers of embedded generation capacity – as was enacted in Britain			✔	✔
Longer-term investments				
Aggressive deployment of end-use efficiency measures to reduce overall demand – for instance, heat pumps to replace resistive electric heat and improvements in home insulation would be helpful in Texas	✔	✔		
Expanding linkages with neighbouring systems to expand options in face of extreme events – by 2026, South Australia is due to deliver a major expansion of interconnector capacity with the neighbouring New South Wales system	✔			✔
Reducing impact of events				
Implementation of smart distribution level technologies and smart pricing to allow the grid operator to selectively interrupt small groups of customers in sequence for limited periods to minimise disruption	✔			
Better sectionalisation of the distribution system to allow more targeted control over what demand gets protected (e.g. critical infrastructure) and what is available for rotating interruption	✔			

Common themes and talking points to counter myths after events

- The vast majority of supply loss stems from problems with wires – chiefly at distribution grids.
- The well-understood challenges for reliable system operation presented by renewables can be readily managed in the plans and operations of a responsible and effective system operator.
- Regulators and policymakers have a role to ensure regulations and policies support the efficient accommodation of these new technologies, such as making sure generation is not excessively prone to tripping with changes in grid frequency, and unlocking new sources of inertia to readily absorb changes in frequency.

Annex I – Primer on reliability and resilience

Reliability is (or should be) defined by the interests of consumers (residential, commercial and industrial). The 'right' level of reliability balances the value of increased reliability against the cost of achieving it:

- What is the expected cost to me of being without electricity given the expected frequency and duration of such an event?
- How much would it cost to be able to expect fewer/shorter interruptions?

Differences in root causes between service interruptions are of no interest to consumers – they're technical details for 'the authorities' to worry about. Yet different standards for reliability have developed separately.[27] Consumers' experience is reflected in metrics that track the frequency and duration of service interruptions per customer per year from all causes. There is often no formal standard, but the data reveal an implicit standard of reliability to which consumers have become accustomed over time. For networks, this typically ranges from tens of minutes to hundreds of minutes per customer per year.

Generation supply, on the other hand, is measured against a standard for the frequency or duration of service interruptions specifically attributable to supply shortfall. The metric most commonly employed stipulates the cumulative 'hours' or 'events' of interruption, omitting any gauge of the severity of an individual event. Although it is not possible to make a definitive comparison between the two standards (networks and generation supply), the supply standard can be conservatively interpreted as tens of seconds of interruption per customer per year.

There is therefore an obvious mismatch between the generation standard and the standard of service consumers have come to expect, with the mandated reliability of the generating resources vastly exceeding consumers' lived experience. This leads to a misallocation of limited resources between generation and networks, a mismatch that is exacerbated by under-valuation of energy efficiency measures and the innate flexibility of many sources of demand, and by the learned tendency of public media to be less strident about all-too-familiar network-related events (indeed, to be all but oblivious to the commonality of local distribution system events) than about exceedingly rare supply-related events (which in reality occur at a rate far less frequent than even what the standard would dictate). Although there is no reason why the standard of supply reliability should be expected to diminish as more variable resources enter the grid, this historical tendency to overinvest in generation capacity and underinvest in networks and other options will continue to have adverse consequences for consumers. These effects include excess spend through procurement of more generation capacity than required and through an insufficient focus on smart solutions to manage network constraints.

Resilience is a term that is sometimes used in the same context as reliability, but the distinction being drawn (if one is being drawn at all) is not always clear. Resilience becomes a usefully discrete concept when addressing some combination of:

- Ability to resist catastrophic failure of the bulk power grid;
- Ability to carry on providing at least some services once catastrophic failure has occurred; and
- How and how quickly the grid can be brought back into something approaching normal operation.

Resilience deals not so much with the reliability of the power grid as it does with issues of emergency planning and response. The ability to carry on providing some services in the event of catastrophic failure is typically a matter to be addressed by governments, whereas reliability is more clearly

27 These include SAIDI (System Average Interruption Duration Index), the total duration of interruptions for a group of customers, and SAIFI (System Average Interruption Frequency Index), a system index of average frequency of interruptions in power supply.

a matter to be addressed by system operators, albeit subject to applicable public policy.

Conversations about reliability should focus on net consumer benefits. Consumers can little afford the practice of investing in generation margins that offer imperceptible improvements in service reliability when investing in networks; other options would deliver more value for money. Reliability can also be achieved, at lower cost, by reducing demand through energy-efficiency improvements, and by enabling consumers to benefit from shifting innately flexible consumption to periods when supply is plentiful and cheap. Consumers should be the ultimate arbiters of what constitutes an acceptable and cost-effective standard of reliability.

Annex II – Application of checklist to case study of Texas 2021

This section shows how the checklist can be applied in practice using the case study of the Texan event in February 2021.

a. Demand and supply – what was the background?

- ❑ Demand at the onset of the winter storm event, driven by heavy reliance on resistance heating, was above the extreme winter contingency level, more typical of Texas's demanding summer conditions, and demand peaked at the highest level on record during the event.
- ❑ Supply was initially scarce but sufficient to meet the record demand, but within hours nearly 50% of planned generation failed, mainly gas-fired but also 40% of coal and one of four nuclear units.
- ❑ Wind supplies, on average, over 20% of Texas's annual electricity, and over half of the wind fleet was out of service. But the system operator plans on only about 20% of potential wind production (about 7 GW) under severe winter conditions. In this event, the fleet operated on average at a bit more than 10% of potential (about 4 GW).
- ❑ Unlike other regions of North America, Texas's grid is effectively an island, electrically isolated from neighbouring systems for historical reasons. As a result, there is limited ability to mitigate events by broadening the supply solutions. That said, as the crisis affected a broad swathe of the midcontinent it is unclear just how much help would have been available.

b. What appears to be the root cause(s) based on best available information?

- ❑ The event was precipitated by a winter storm of historically rare, but not unprecedented, depth and duration. The weather drove demand to unforeseen levels, and some amount of rolling interruption over a few hours would likely have been necessary in the best case. In the event, the rapid failure of nearly 50% of planned generation early in the hours of 15 February, overwhelmingly by gas-fired generation, brought the system within minutes of collapse. The plant failures were caused by a combination of inadequate freeze protection at the plants themselves and in the fuel supply infrastructure on which they rely. Regional gas production fell by about 50% before beginning to recover. This was all largely unforeseen. Reliance on wind generation was not a major factor.

c. What is the relative severity of the event?

- ❑ This was an extremely serious event. More than 4.5 million customers lost power, many for three days or more. The severe conditions, in a region heavily reliant on resistance electric heat, led to more than 100 deaths and billions of dollars in property damage.

d. What was the system operator's resource plan for meeting demand under the relevant circumstances (assuming there was one)?

- ❑ Demand exceeded the system operator's extreme winter planning scenario. Available resources at the onset of the storm were roughly in line with that scenario and were stretched to the limit to meet demand. Around 90% of planned generation was fossil and nuclear, three-quarters of that being natural gas. While the system operator would likely have had to resort to some level of rolling interruptions for a few hours as the storm continued through the week, they would probably have averted any truly dire consequences had the generation fleet held up as planned. In the event, of course, that did not happen.

e. What was the expected role for renewables in the relevant contingency plan?

- ❑ The plan called for about 7 GW (out of an installed capacity of about 32 GW) of wind generation to meet 67 GW of demand, so about 11% of total resources.

f. To what extent did the system operator plan for and deploy demand flexibility?

- ❑ It is not clear how much of the approximately 20 GW of 'unserved demand' was voluntary. Wholesale prices famously hit the cap of $9,000/MWh and stayed there for several days, but penetration of dynamic retail pricing is limited and metering infrastructure is not up to best-in-class standards. A different form of flexibility – the ability to selectively interrupt small groups of customers in sequence for limited periods to minimize disruption – was drastically limited by distribution system architecture that placed large amounts of load off-limits to protect specific critical customers. As a result, millions of customers were without power for days while millions of others never lost power at all.

g. How exactly did the PLAN fail – what was supposed to have happened that did not (NOT what renewables didn't do that they weren't expected to do)?

- ❑ Thermal generation – that was reasonably expected to operate – failed, largely because of its reliance on natural gas infrastructure that was far more vulnerable to severe winter weather than either the system operator or the regulator anticipated. Most of the wind fleet was also frozen, and that's an issue for the future, but that was largely expected and accommodated for in plans.

h. What false claims are being promoted by fossil industry players and their enablers?

- ❑ Fossil industry actors, including the state's natural gas regulator, were quick to point to Texas's rapid uptake of wind over the past 20 years and the large amount of wind generation (about 18 GW of the 32 GW installed) that was offline at the time. The narrative bounced between Texas's wind fleet's vulnerability to freezing and the effect of low wind speeds during cold winter weather on the dispatchability of wind.

i. Why exactly are the claims false?

- ❑ The fact that the system operator's plan accounted for both of these factors – frozen wind capacity and low wind speeds during cold winter weather – and that they therefore had little to do with why the disaster occurred, went conveniently unmentioned. The claims are a familiar mix of factual snippets removed from context, woven into an intentional misrepresentation. One difference in this case, unfortunately, is that the event was legitimately catastrophic, contributing to many deaths.

j. What are the legitimate transition-related challenges manifested in the event?

- ❑ The continued reliance on fossil fuels in the system operator's plan to deal with these circumstances is unsatisfactory. The fact that the Texas renewables resource is so reliably unreliable under these circumstances is also unsatisfactory. Both of these challenges call for smart solutions, including on the demand side, and there is too much magical thinking among advocates (about batteries, for instance, which would have been of very limited benefit in this situation).

k. What best practices could a prudent system operator have deployed to avoid the event?

- ❑ Better scenario planning based on available historical information.
- ❑ Stronger oversight and 'no excuses' enforcement of operational standards for critical resources, including the upstream infrastructure on which they rely.
- ❑ Planned, accelerated reduction of dependence on fossil fuels.
- ❑ Aggressive deployment of building efficiency investments, smart distribution-level technologies and smart pricing to access the value of flexible loads.
- ❑ Better sectionalization of the distribution system to allow finer control over what gets protected and what is available for rotating interruption.
- ❑ Increase the Texas grid's linkages with neighbouring systems to expand options for dampening the impacts of such events in future.

Annex III – Glossary

- **Alternating current** – the grid operates on a current which periodically reverses direction and changes its magnitude continuously with time
- **Blackout** – total collapse of the grid
- **Dispatchable** – resources whose energy production or consumption can be controlled and changed according to the needs of the system
- **Embedded generation** – electricity production capacity connected to a distribution rather than transmission network
- **Flexibility** – describes the degree to which a power system can adjust the electricity demand or generation in reaction to both anticipated and unanticipated variability
- **Inertia** – a service that slows the rate of decline in system frequency, traditionally supplied by large, heavy machines at power plants and industrial plants, rotating synchronously with the frequency of the alternating current, but increasingly with new and innovative green sources being unlocked
- **Reliability** – reflects the extent of interruption to services. An economic ('the right') level trades off the expected cost to being without electricity against the cost of reducing expected interruptions.
- **Resilience** – relates to abilities to resist catastrophic failure of the bulk power grid, to carry on providing at least some services once catastrophic failure has occurred, and to quickly bring the grid back to normal operation
- **Rolling/rotating service interruption** – when the system operator selectively orders groups of customers to be interrupted for limited periods of time in sequence while also protecting designated critical loads and ensuring operability of the grid
- **System frequency** – reflects how frequently the electric current alternates on the grid, noting most things connected to the grid are designed to operate safely based on a defined expected range of system frequency
- **System operator** – the designated 'traffic cop' of the electricity highway – to ensure that demand and supply are balanced in real time

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