Operating the Power Grid During a Pandemic

COVID-19 Experiences

IN EARLY 2020, COVID-19 STARTED TO IMPACT SOCIETY AT A global scale. The World Health Organization declared COVID-19 a pandemic on 11 March 2020, and the world faced the most significant health problem of the last 100 years. The pandemic and its lockdown measures caused significant disruptions to society and the economy. Electricity is essential to modern society and the power grid is considered the most critical infrastructure, with essentially all other infrastructure dependent on it. Maintaining grid reliability and resilience was paramount during the pandemic.

Grid operators and electric utilities worldwide rose to the challenges brought by COVID-19, mitigated the pandemic's effects and risks to power systems, and protected employees' and customers' health while keeping the lights on, providing reliable power to communities. This article captures the following operational experiences during this pandemic:

- ✔ Control center continuity
- ✔ Impact on load
- ✔ Impact on generation
- ✔ Impact on transmission and distribution
- ✔ System operational challenges
- ✔ Impact on electricity markets
- ✔ Communication and workforce impact.

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Control Center Continuity

Control center operations are a crucial part of grid operation, necessary for balancing generation with load and ensuring system reliability around the clock. Maintaining control room operations is particularly challenging as control room operators work together in close quarters, which increases chances for exposure. Operators are highly specialized and not easily replaced if infected. Control room operators' health and availability were a major concern at the start of the pandemic. Strict hygiene measures, sanitization protocols, and physical separation were implemented globally in control rooms to ensure that the chain of infection was broken as early as possible.

Grid operators generally have a primary control center and a backup control center for emergency use. Some system operators, such as PJM Interconnection, a regional transmission organization (RTO) in the eastern part of the United States, and the Australian Electricity Market Operator (AEMO), for example, operate dual primary control centers continuously at separate geographic locations so that there is negligible impact in case of a control center disruption. As a part of the pandemic response, most of the power grids operated with both primary and backup control centers to increase redundancy and maintain physical distance at their control centers. Some even used other facilities as additional control rooms to provide flexibility and options to separate dispatch teams.

In general, all in-person access to the control centers were suspended except for control room operators to reduce staff risk of exposure. In some control centers, shift length was extended from 8 to 12 h to reduce exposure during staff changeovers. Many grid operators split control room staff into separate teams, which offered physical separation to minimize spread of the virus. Some rotated shifts between different control centers to enable no-touch handoffs and isolation of crews from one to another. Some system operators relied on sequestration to prevent contagion and ensure continuity of operation. Many organizations had operators move to other departments, and some brought these operators back to support operations. Some operators added support staff to complement control center operations remotely. Table 1 summarizes the practices of different regions.

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Control room operators' health and availability were a major concern at the start of the pandemic.

PJM added a third control room to supplement existing control centers by repurposing the operator/dispatch training simulator. All three control rooms function together as a single virtual control room, and each facility is capable of operating the entire system independently if the others are compromised. For 11 weeks in 2020, PJM sequestered a group of dispatchers to operate from the newly created control room to ensure the availability of a full shift if the virus were to spread. Based on the trending infection rates, hospitalizations, and related statistics in Pennsylvania, PJM moved its operators into sequestration for a second time from December 2020 through March 2021. The dispatch shifts changed from 8- to 12-h shifts, and outage studies were performed remotely.

In Australia, strict protocols were put in place to ensure continuity of operations, both in the National Electricity Market (NEM), covering eastern Australia, and the Wholesale Electricity Market (WEM), covering western Australia. The NEM has two control rooms in two different states, and while there is an allocation of specific regions to each control room, either is able to operate the whole NEM if required. Furthermore, there is capability to operate the NEM from alternative locations. The WEM has one primary control room and a backup control room. The backup control room received additional investments at the start of the pandemic and became a second fully operational control room. Operators were segregated to operate from different control rooms during day and night, and the separation was designed so that they would not come into contact with each other. All critical staff were issued letters that allowed them to work without restrictions during lockdowns.

In general, transmission system operators (TSOs) across Europe implemented a doubling of staff to ensure continuity in the national main control centers and national backup control centers. Organizational measures were established and applied depending on the severity of the situation, including

- ✔ restricted access to control rooms
- ✔ partial confinement (requested to limit contacts to their families)
- ✔ total confinement (operational staff stays inside the control room without any contact outside) of operational staff in control room
- ✔ parallel work of two control rooms (primary and backup)
- ✔ operational staff divided into separate teams with no mixing between them
- ✔ teleworking for noncore activities.

In India, continuity of control center operations was maintained at the state, regional, and national levels. Office premises were more frequently sanitized, and control room personnel were equipped with personal protective equipment kits to minimize spread of the pandemic. The National Load Dispatch Center (NLDC) and regional load dispatch centers (RLDCs) issued guidelines regarding rotation of duties of staff, work-from-home protocols, and necessary safety precautions for personnel involved in real-time system operation. Alternate control rooms existed at each RLDC and NLDC in a separate area of the office's premises to minimize person-to-person contact during shift changeovers. The hand-off during a shift change was also remote to reduce physical interactions.

table 1. A summary of control center practices.

	PJM Interconnection	Australia	Europe	India	Brazil
Restricted access to control room	Yes	Yes	Yes	Yes	Yes
Dispatch shift changes	12-h shift, remote shift handover	Separate dispatch teams with no mixing	Doubling of staff, separate dispatch teams with no mixing, remote shift handover	Remote shift handover	12-h shift
Control rooms	Added the third control room	Primary and backup control rooms	Primary and backup control rooms	Added alternate control rooms	Control room action plan
Operator sequestration	Yes	No	Partial or total confinement	No	No
Remote work	Ninety percent of employees	Noncritical activities	Noncore activities	Noncritical activities	Noncritical activities

The Brazilian National System Operator (ONS) manages five control centers (one national, four regional). A Control Room Action Plan was prepared to ensure the safety and health of real-time staff and secure operational continuity of the control centers. The safety and health measures included restricted access to the control room, permanent hygiene measures, testing, and 12-h shifts. The operational continuity measures included special training of the real-time operation staff to deal with stress and the absence of other colleagues, and analysis of contamination scenarios that would have made it impossible to run a control center. ONS replaced three of its five executive directors during the pandemic, which took the office on a fully remote schedule in May 2020, thus adding complexity to meeting the pandemic-related challenges.

Impact on Load

Changes in human behavior are constantly impacting the grid. As large swathes of the population followed stay-at-home orders at the beginning of 2020, a significant and varying amount of load reduction and changes in load profile were noted in different countries around the world.

In the United States, load started to drop across the country as stay-at-home orders were issued. Many grid operators noted a delay in the morning and afternoon peaks due to school and business closures. Generally, the amount of power used by businesses was declining, while residential consumption was rising when people were working from home. In the absence of a commute, they got up later and worked more consistently over the course of the day. On a macroscale, many regions experienced load levels comparable to those on weekends. For the regions with high renewable penetration, the "duck curve" effect was exacerbated for the days when renewable output was at peak levels.

In PJM, in mid-March, as businesses, schools, and other consumers began closing or sending employees to work from home, energy-usage routines began to change. PJM's observations from 17 to 19 March show the morning peak arriving 1–2 h later than forecast models typically predict, shifting from roughly 8 a.m. to 9 to 10 a.m., with both the morning and evening peaks approximately 5% lower than expected.

PJM estimated the COVID-19 impact on daily peak load and energy for 2020, as shown in Figure 1. Total energy use was dampened. The impacts were most severe in spring 2020. Figure 2 depicts RTO daily peak load for 2020 and 2021 compared to 2019. At the beginning of 2021, the weekday peaks were reduced by approximately 1%. Later in 2021, daily peaks were back to prepandemic levels.

In Australia, where there is the highest degree of distributed energy resources in the world, and on average, one in every three houses has a rooftop photovoltaic (PV), changing load profiles could present many challenges. A reduction by 25% in load could have pushed the Australian power system to a heightened state of risk in terms of controllability of the grid.

With major cities going into lockdown, some initial reductions in load were experienced in the NEM. However, as people began to work from home, these reductions were contained and the load returned to its prepandemic levels after the initial weeks of the pandemic. The AEMO created models to separate the impact of COVID-19 from other factors such as temperature, humidity, day of the week, time of the year, and power exported to the grid from behind-the-meter PVs. In the NEM, the greatest impact was noticed in the second quarter of 2020. However, this impact was not similar in every sector or every state of the NEM. There was a minimal change in the load patterns of large industrial loads as they

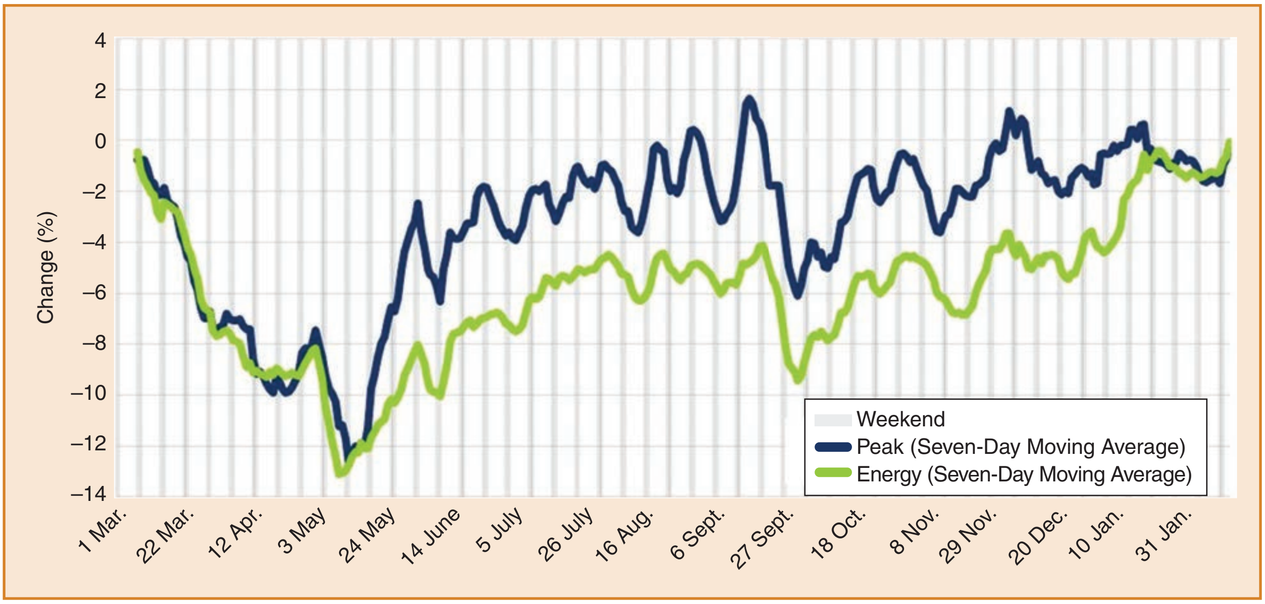

figure 1. The estimated COVID-19 impact on daily peak and energy for 2020.

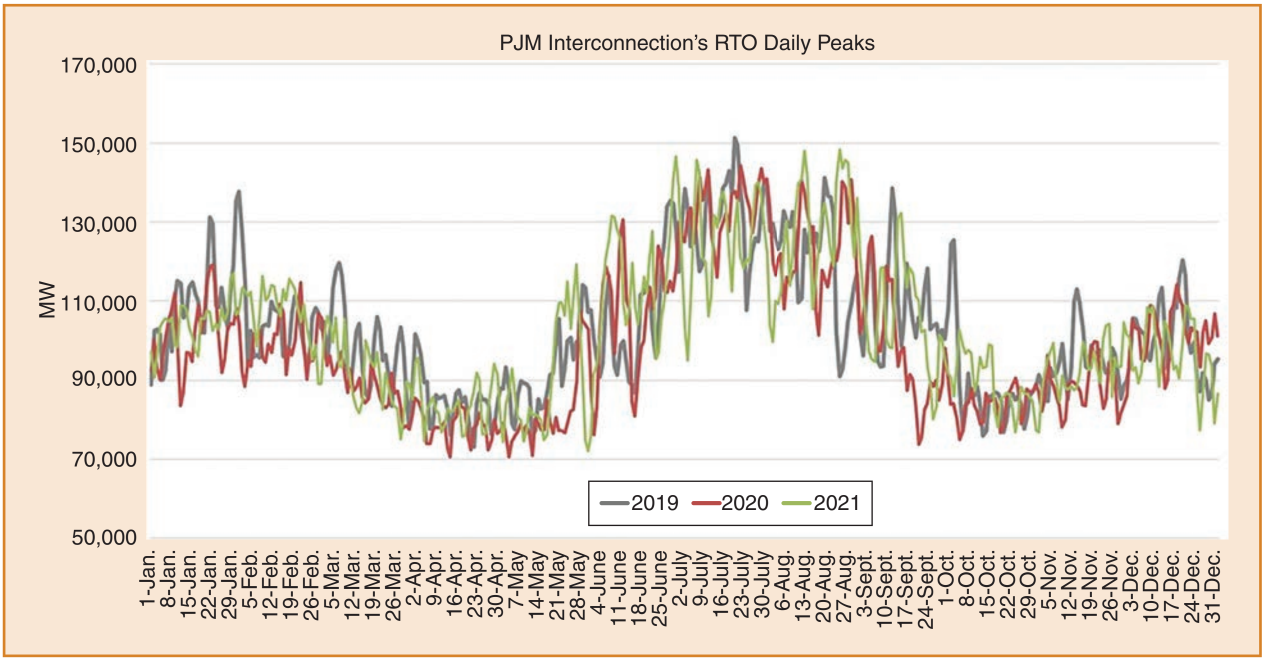

figure 2. PJM Interconnection's RTO daily peaks.

remained mostly operational during the lockdown periods of 2020. The commercial sector reduced their demand as lockdowns in the cities affected their operations. On the other hand, residential consumption increased as people started working from home. In Victoria, where the lockdowns mainly affected commercial businesses, there was a reduction in load in that sector, but this was offset by an increase in residential load.

COVID-19 restrictions affected New South Wales's and Queensland's load more than other states of the NEM. In those two states, reductions in commercial load and mild weather (which limited the COVID-19-related increase in residential load) ensured reduction in load (–5% on average). With a relaxation of lockdowns, the load was back to its normal patterns in May and June. Queensland's load impact was more or less similar to New South Wales's.

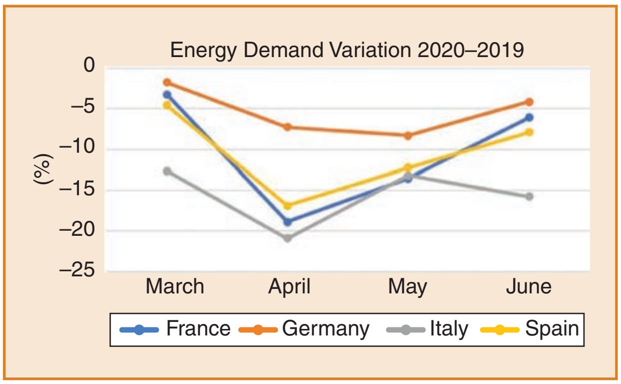

figure 3. The monthly energy-demand variation for some European countries in 2020 versus 2019. (Source: European Network of Transmission System Operators for Electricity.)

The AEMO undertook an analysis in the Western Australian WEM to compare operational load quantities and patterns during the pandemic for the same period in 2019 to identify any nonpandemic-related changes, such as weather or the impact of behind-the-meter PVs. A reduction of approximately 6.5% was experienced in the morning peaks for workdays in the first couple of weeks, with slight increases throughout other hours of the day. The reduction in the morning peak was due to people not having to be ready for a particular start time in the morning, and it was an expected trend. For nonworkdays, the load increased slightly throughout the day. The most significant increase occurred at midday, with 6–7% on average. As people were working from home they used more energy, and this reduced their PV export to the grid; therefore, the operational load increased. With the easing of pandemic restrictions, despite some minor changes to consumption patterns, the overall impact on load was negligible compared to 2019.

In Europe, the impact led to a general decrease of the consumption in almost all countries. Figure 3 shows the monthly energy-demand variation in 2020 versus 2019 during the most critical period of the pandemic (March–June) for the four countries with the largest energy consumption in continental Europe. All of them faced a decrease in energy consumption, and the most affected ones reached a variation up to –20%. April appears to be the most critical month, when the hardest lockdown measures were in force in many countries.

In Italy, the hourly load profile in Figure 4 shows how restrictions imposed at the national level in the beginning of March caused a reduction in load. This reduction lasted until the end of May because of the duration of some restrictions, especially in the tertiary sector. This led to a general reduction in consumption for all the different clusters of consumers. The Italian TSO reported that in April the large industrial loads faced a variation of –34% compared to 2019, the railway sector a variation of –60%, while the domestic and tertiary sectors experienced a variation of –17.8%. However, the latter is responsible for the highest load reduction in absolute values, reaching up to 60% of the total load decrease in the month of April. The hourly load profile also changed. In the weekdays, the load variation affected all the hours of the day but with the highest decrease during peak hours. During the weekend. the consumption decrease became more homogeneous, without significant changes in the hourly profile.

The higher share of nondispatchable renewables impacted the hourly load profile, resulting in the duck curve profile of the net load balanced by dispatchable generation. Figure 5 reports the average load profile of the net load in the month of April. It is noted that in 2020 the duck curve was present, especially during weekends and public holidays.

In India, a lockdown was implemented in March 2020 and resulted in the reduction of all-India electricity demand by 25–30%, as compared with the same period in 2019. This was mainly due to the shutting down of a large chunk of industrial, commercial, and traction loads. All-India energy met in 2020 in comparison to that which was met in 2019 is presented in Figure 6. The extended lockdown measures ended at the end of May 2020, when an increase in all-India energy consumption occurred. By July 2020, energy consumption returned to almost prepandemic energy levels. The end of the year was marked by a recovery of electricity demand, above 2019 levels after a weather adjustment, as shown in Figure 6.

Electricity load in China dropped quickly under the lockdown in January and more significantly in February (–13% compared to February 2019). A part of the difference was due to February being significantly colder in 2019 than in 2020. After weather was corrected, the decrease in load in February 2020 compared to February 2019 was still significant at –11%. As lockdowns were eased, electricity load showed the first signs of recovery. From April 2020, electricity load in China recovered completely and returned to prepandemic levels. From August 2020 onward, the weather-corrected load was systematically 6% higher than 2019 levels.

The COVID-19 pandemic hit Brazil in late February 2020. The pandemic led to an immediate consumption decrease of industrial and service segments. There was also a significant change in the load profile of business and residential consumption on working days due to home office measures. In some months, Sunday load profiles became typical days for operational planning purposes. Figure 7 presents the country's load profile in 2019 and in the first days of COVID's State of Emergency Decree.

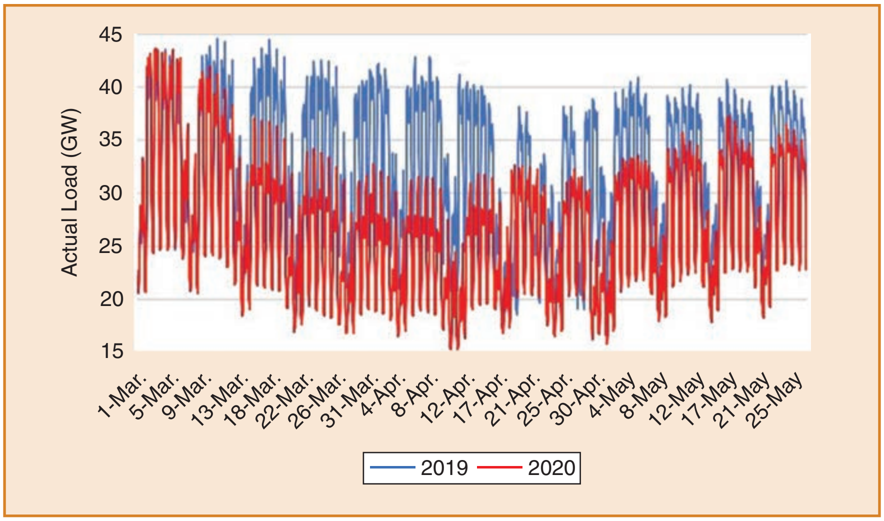

figure 4. The hourly load profile in Italy, 2020 versus 2019. (Source: European Network of Transmission System Operators for Electricity.)

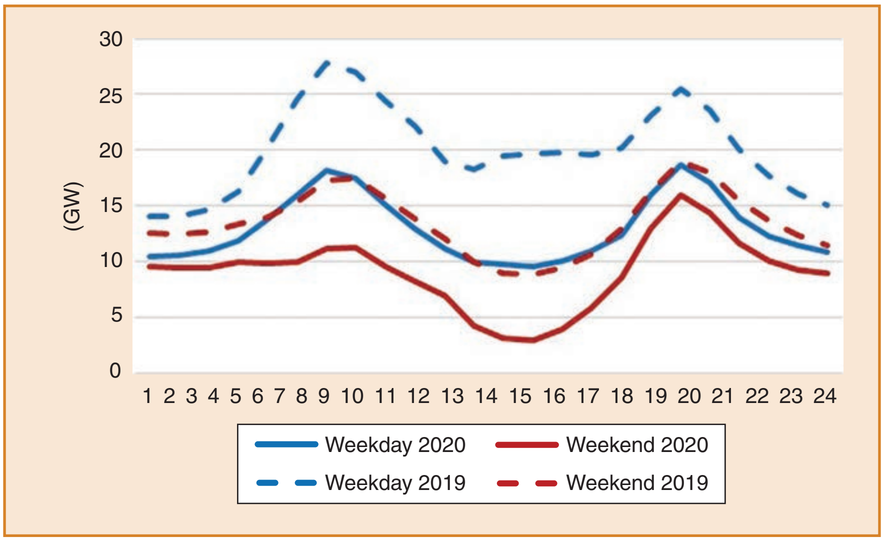

figure 5. The average load profile of residual load in Italy in April, 2020 versus 2019. (Source: European Network of Transmission System Operators for Electricity.)

In 2020, electricity consumption dropped 1.5% with respect to 2019.

Impact on Generation

The COVID-19 pandemic affected power generation in various countries differently. A common finding is that generation outages were impacted, overall generation declined due to lower load, and power mix shifted toward renewables.

The spring season is typically the maintenance outage season in PJM. At the beginning of the pandemic, PJM worked with generation and transmission owners to reschedule the planned outages to prevent them from potentially turning into larger disruptions. To address equipment issues, PJM issued guidance for utilities stating that utilities should "…not be reliant on another party or even the vendor for immediate spare support" and recommended that they review their plans and check with vendors on delivery lead times. Overall for 2020, the patterns in planned and maintenance outages show that even with the initial decreases in outages during the onset of COVID-19, resource owners were still able to accomplish significant amounts of outage work, either by deferring work to later times in the year or splitting larger planned outages into shorter maintenance outages.

In Australia at the start of the pandemic, there was a concern about generation availability as some of the maintenance work on generators required free movement of experts who were restricted by the lockdowns and interstate and international travel. However, no major impact was felt as governments allowed travel exemptions for critical workers. Therefore, there was adequate capacity available to meet the expected demand.

In Europe, planned outages for maintenance were re-evaluated, postponed, or even cancelled. The pandemic also impacted generation mix. In the United States, natural gas remained the leading source of electricity from March onward, while renewables outpaced the contribution of coal-fired power plants during the spring of 2020 when the stay-at-home order was in effect.

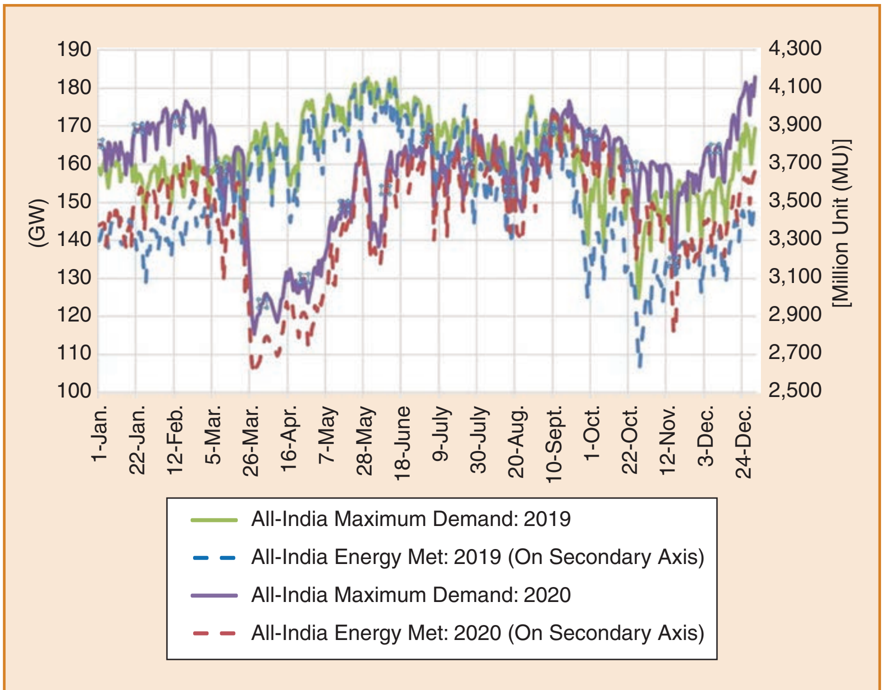

figure 6. All-India peak demand and energy met.

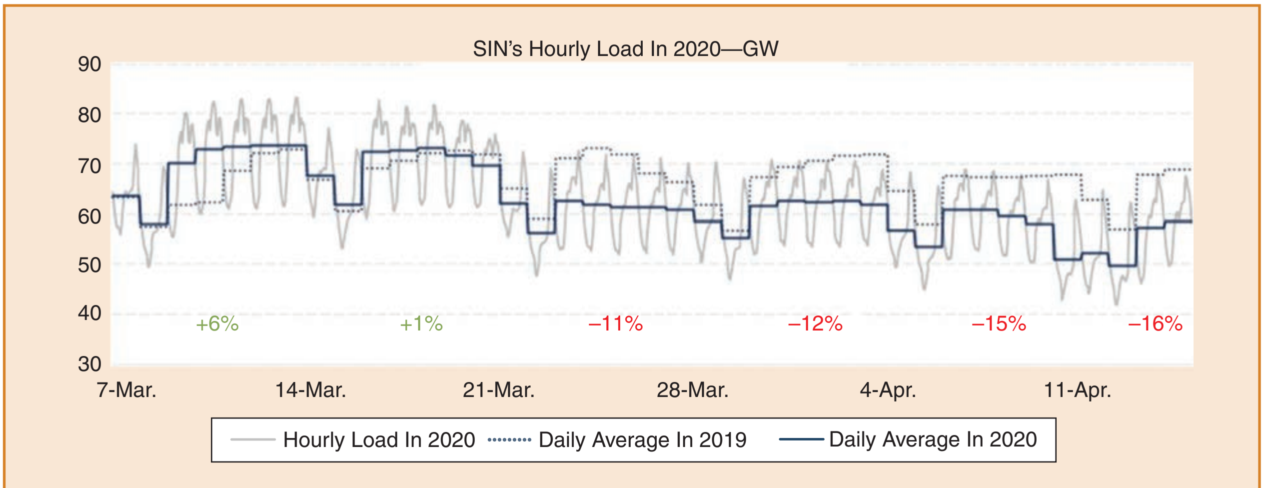

figure 7. The interconnected system hourly load in Brazil, 2020 versus 2019. The differences were obtained through the weekly averages of 2019 and 2020. (Source: ONS.)

Solar curtailment tripled in California ISO (CAISO) in the latter half of March, and wind curtailment increased by more than 50% during the same period. In summer 2020, coal and nuclear generation peaked to respond to load increase. In autumn and winter 2020, renewables followed seasonal trends. Total U.S. energy-related CO_2 emissions fell 11% in 2020, or 570 million metric tons relative to 2019. At a global level, energy-related CO_2 emissions fell 5.8%, or 2 billion tons.

In Italy, the spring is usually a low consumption period, characterized by high shares of renewables. The load reduction in 2020 emphasized the role of renewable generation in supplying the load. Consumptions lower than usual led to a reduction in fossil fuel generation and in imports from foreign countries, pushing renewable generation to a higher share in the mix, up to 51% in May, as depicted in Figure 8. This trend also occurred in other countries in Europe; for example, in Spain and Germany, the renewable energy share was 53 and 58%, respectively, in April 2020.

In Italy, the issue of excessive generation from variable renewable resources was relevant, especially in April 2020, when the excessive generation reached approximately 2 GW in the southern regions. In general, during the period April–June 2020, the Italian TSO faced the operational conditions foreseen for the year 2030, when the European target of decarbonization policies are planned to be achieved.

In India, the gap between coal and renewables significantly narrowed after the first lockdown, with renewables reaching just over 30% in mid-August 2020. Starting at the end of August, the gap started to widen again, following the seasonal trend. By the end of November, the share of renewables in the electricity mix was just below 20%, in line with start-of-the-year, pre-COVID-19 levels.

In Brazil, the main challenge was the management of significant amounts of zero-operational cost generation, including run-of-the-river hydro, environmental minimum-outflow constraints on hydro plants with storage, must-run thermal generation (take-or-pay gas supply contracts), and variable renewable energy production. As shown in Figure 9, roughly 75% of Brazil's energy demand in 2020 was met by zero-marginal cost generation, that is, the Brazilian net load for dispatchable resources was only 25% of the total load.

Impact on Transmission and Distribution

The pandemic impacted supply chains, especially equipment with long production lead times that is typically manufactured internationally. Having the right replacement equipment is crucial for mitigating damages and restoring power in a timely manner. The pandemic impacted the ability of manufacturing companies to maintain the personnel and raw material necessary for producing equipment, which slowed down equipment production across the world.

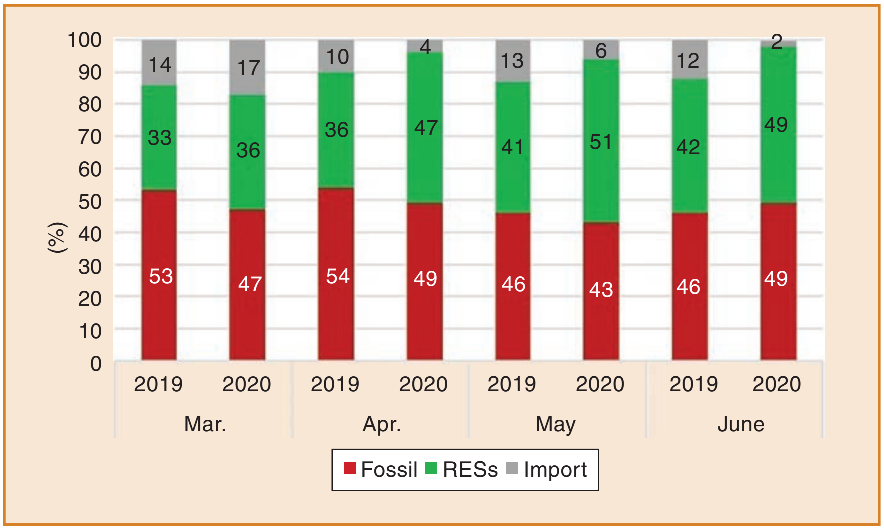

figure 8. The load coverage by source in Italy during the period March–June, 2020 versus 2019. (Source: TERNA.) RESs: renewable energy sources.

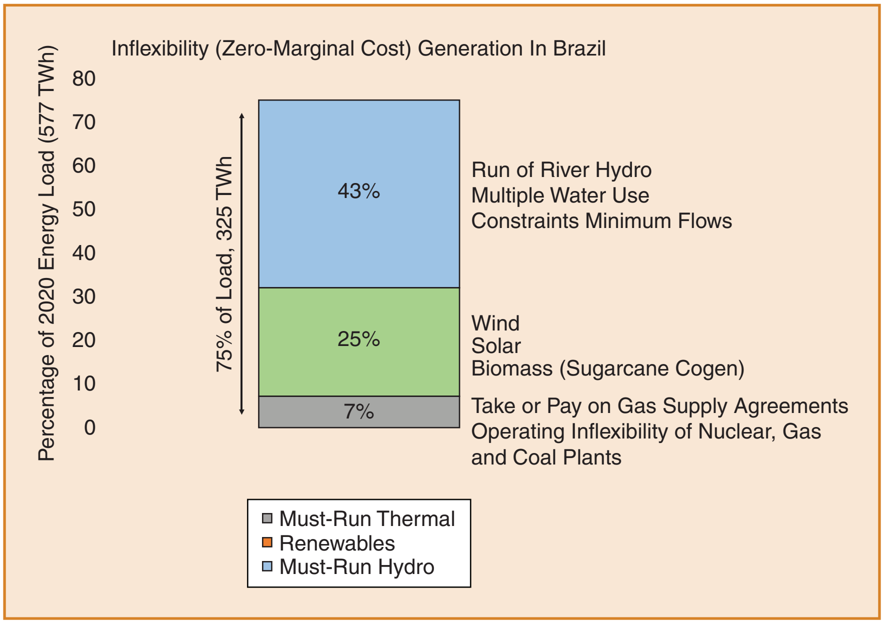

figure 9. The inflexible (zero-marginal cost) generation stack in Brazil. (Source: ONS.)

> System operators globally had been refining load-forecasting to reflect the effect on load from pandemic-related conditions.

In the PJM region, the utilities already had some spare equipment that could be used in an emergency, but margins were thin, largely relying on just-in-time delivery for spares. PJM and the utilities had been taking a holistic approach to identifying issues related to supply chain and fuel security. To get impacted areas up and running quickly, PJM members worked to reduce potential supply-chain lags by prestaging critical assets such as extra high-voltage transformers and other spare equipment and established rapid response plans. In Australia, Italy, and Brazil there were no major transmission or distribution impacts. Fewer transmission outages were scheduled during the lockdown period in India, as illustrated in Figure 10.

During the pandemic, substation automation was used at critical and remote sites, integrated with Internet of Things technologies, significantly reducing the need for people to be present for real-time equipment condition diagnoses and reconfigurations.

System Operation Challenges

During the first few months of the pandemic, system operations were challenging, which included lower load consumption with a different hourly profile and high shares of renewable generation and less thermal generation as well as high-voltage issues caused by lower load levels. A severe drought also affected Brazil, a country with significant hydrogeneration, which introduced particular challenges.

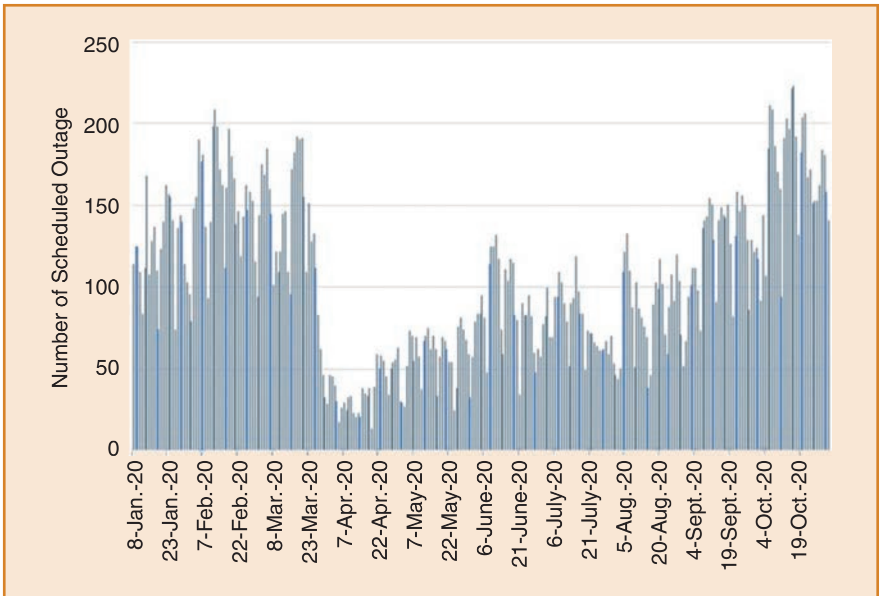

figure 10. The number of scheduled outages in India.

When the widespread shutdown of business began due to stay-at-home orders, load-forecasting errors increased due to a lack of historical statistical data for a pandemic event. System operators globally had been refining load forecasting to reflect the effect on load from pandemic-related conditions.

PJM used traditional forecasting models to look back at expected loads, plugging in the actual weather conditions and noting the difference in actual peaks and energy usage from what the models would normally forecast. This adjustment helped to refine load forecasting and adjust operation scheduling during the pandemic. Over time, load forecasting began to pick up on new trends. On Monday, 16 March, for example, PJM would normally have expected roughly 100,000 MW of load. With the special circumstances caused by coronavirus restrictions, the forecast was lowered to roughly 94,500 MW, and the actual load came in at approximately 95,500 MW. PJM operators have been able to make refinements to the forecast that greatly increase its accuracy, and the forecasting models continue to learn from these conditions and improve as well.

Load changes constituted a big forecasting challenge for all TSOs in Europe. In Italy, the TSO optimized its load forecast. The daily mean absolute percentage error in 2020 was affected by system conditions, but the average value over the period March–April was in line with previous years and below 2% (1.99% in 2020 versus 1.74% in 2019).

Excessive generation was experienced in regions with high renewable penetration. In CAISO, solar curtailment tripled in the latter half of March, and wind curtailment increased by more than 50% during the same time period. In Italy, hydropumped storage was extensively used during the day to tackle excessive generation, store the excess energy, and release it during the evening ramp. The "last resort" was renewable curtailment.

A reduced level of thermal generation also decreased available reserves and ancillary services (such as inertia and voltage regulation). In Italy, to guarantee enough conventional generation, the TSO reduced the amount of imported energy in many critical hours and had frequent redispatching after the day-ahead market to procure enough reserves and ancillary services. In March 2020, volumes dispatched by the TSO increased by 59% and upward volumes increased by 31%, while downward volumes increased by 113% compared to March 2019. The same trend occurred in April: the upward volumes increased by 52% and downward volumes increased by 125%. These activations were mainly due to the procurement of reserves and voltage regulation as well as to the management of pumped storage to tackle the excessive generation. Additional volumes procured in the ancillary services market led to a general increase of system operation costs, partially mitigated by lower costs for oil and gas.

Many regions in the world (United States, Europe, Australia, and Brazil) experienced high system voltage (overvoltage) during the spring light-load period with the pandemic, and the following measures were applied:

- ✔ turning on automatic voltage control systems
- ✔ switching off capacitors
- ✔ switching on reactors and synchronous condensers
- ✔ switching off some of the 500- and 220-kV transmission lines during low-load periods
- ✔ opening 800-kV dc links to reduce voltage in Brazil
- ✔ utilizing static synchronous compensator and unified power flow controller devices to absorb reactive power
- ✔ operating generation plants to absorb reactive power and adjust power system voltage.

From late 2020 to late 2021, Brazil also faced its worst drought in a century. With very low inflows and a reduced load, hydro-minimum outflows, which occur for multiple uses of water, contributed to a fast depletion of its hydro reservoirs. The large volume of must-run generation formed the bulk of the supply stack to meet the (reduced) load and then did not allow dispatch of thermal resources to save water in the reservoirs. The drought hit the southeast region severely, where 70% of the hydro storage and load is, thus depleting hydro reservoirs and threatening the security of energy and peak supply in 2021.

The management of this severe drought during the pandemic required a strong multi-institutional and multisector coordination to ensure a security of supply that demanded significant leadership from ONS. From the supply side, a multi-institutional and interministerial joint effort undertook many actions to reduce minimum hydro outflows in a cost-effective way, minimizing environmental impacts. This effort allowed an increase of the thermal dispatch in a merit order to save water. Based on a cost-benefit study, some assets of the bulk transmission grid were operated under an N-1 instead of the practiced N-2 reliability criterion. This change increased the operation risk—which was also affected by an increase of fires during the drought—but produced a 30% gain in transmission capacity that allowed for electricity imports from other regions to the southeast. Operating under an N-1 reliability criterion uncovered several existing inactive grid constraints that restricted power flows. Approximately 40 operational measures and special protection schemes were implemented to handle such constraints and unlock the full potential of an N-1 operation. Imports from neighboring countries and reintegration of dismantled generation compounded the efforts.

From the demand side, a price-based voluntary demand response for industrial and commercial consumers focusing on peak supply reduction was implemented. Residential customers were also provided price signals via a price adder on top of the retail tariff, indicating a scarcity, and were also offered a financial bonus for bigger load reductions.

During the pandemic, Brazil overcame this severe water scarcity through the success of these measures combined with a fairly wet season in 2021–2022. The power system met a consumption growth of 4.1% in 2021. Figure 11 shows the evolution of the stored energy and energy spot prices in the southeast region. The energy spot prices increased as a consequence of the water scarcity, reaching the regulatory cap.

In addition to the challenges mentioned previously, many systems also had to face external events like natural calamities

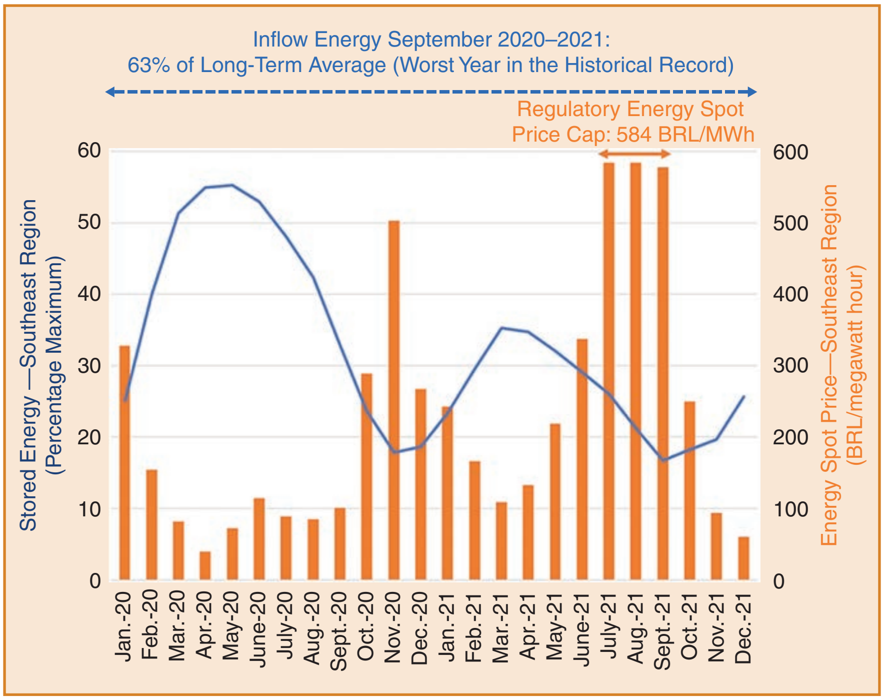

figure 11. The storage level and spot prices of the Southeast region of Brazil. (Source: ONS/CCEE.)

and other phenomena. For instance, India had to plan for the 5 April 2020 (9 p.m. 9-min) lights-out call by the Honorable Prime Minister as a solidarity measure in the fight against the pandemic. A 32-GW demand reduction and subsequent rise was successfully handled through meticulous planning. This was achieved by utilizing fast-ramping capability of hydro- and gas-based generators, keeping voltages under control by the switching of lines, lower droop settings in generation plants, and implementing automatic disconnection at a higher frequency for wind-based generation plants. Likewise, May 2020 and June 2020 witnessed two cyclones and one annular solar eclipse that required careful operational planning in India. This included the utilization of fast ramping from hydro-/gas-based generation, bringing additional units on bar to create reserves, and keeping adequate reactive margins.

Impact on Electricity Markets

Electricity markets operated normally during the pandemic. The fall in energy consumption during the lockdown period had a direct impact on electricity market outcomes. The reduced electricity demand generally resulted in price decreases.

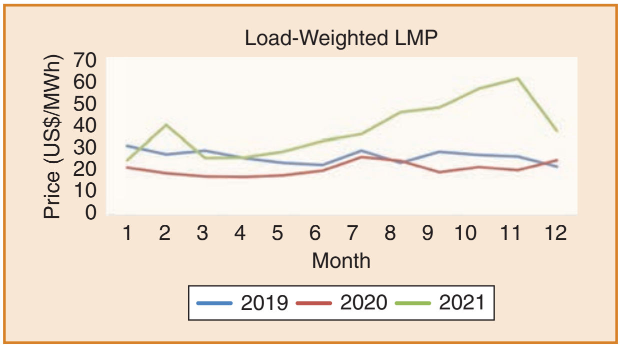

figure 12. The load-weighted locational marginal price (LMP) at PJM Interconnection.

Figure 12 presents the load-weighted average locational marginal price (LMP) at PJM from 2019 to 2021. Average LMPs were much lower in spring 2020. Price drops were also observed in other U.S. independent system operators (ISOs).

In Europe, the reduced load consumption resulted in a lower demand in the day-ahead market in many countries, with a severe impact on electricity prices. In Italy, the average value of the uniform purchase price in March and April 2020 was 28.45 €/MWh, while in 2019 it was 53.11 €/MWh, with a variation of −46%. Figure 13 reports the price difference of the daily average price between 2020 and 2019, as a percentage with respect to 2019, for Italy and Germany.

In Germany, the average day-ahead electricity prices were less than half of the averages observed in the same period of previous years, along with more frequent negative price incidents. Especially in the second half of April, the amount of renewable energy infeed from solar PVs and onshore and offshore wind increased significantly, causing negative day-ahead price incidents.

In Australia, lower spot prices and increased occurrences of negative prices were experienced in the WEM. However, the reduction in fuel prices in the beginning of the pandemic was the more prominent contributor to low energy prices, followed by reduced demand.

In India, the pandemic had an impact on prices in the day-ahead market, which touched a low of Indian Rupee (INR) 600 per MWh on 25 March 2020 (the first day of nationwide lockdown). The monthly average prices for the months of January and February 2020 in the day-ahead market were approximately INR 2,860 and INR 2,914 per MWh, respectively. The prices remained between INR 2,000–3,000 per MWh during the lockdown and recovered later in the year. India also rolled out the real-time market with effect from 1 June 2020, which is a double-sided auction run 48 times a day 1 h before the dispatch period. All the coordination between the system operator and the power exchanges as well as software testing was done remotely and the real-time market rolled out smoothly.

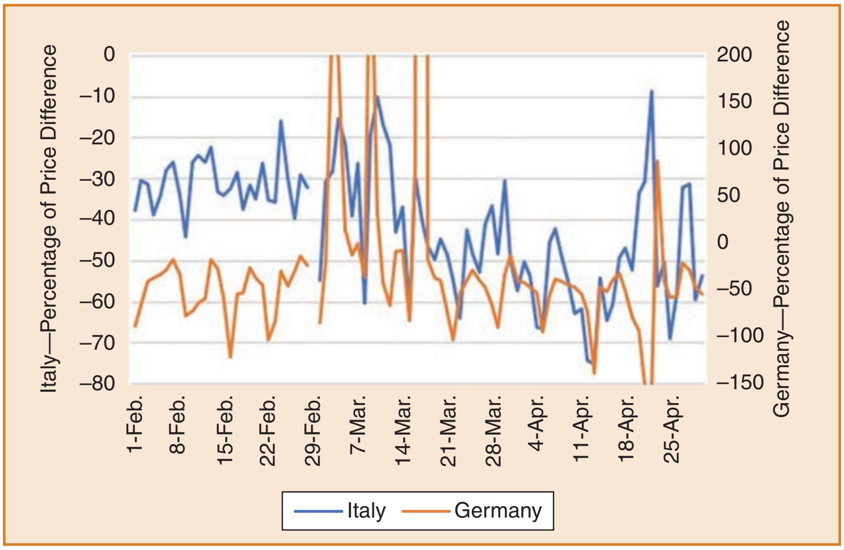

figure 13. The difference in daily average market price, 2020 versus 2019.

Communication and Workforce Impact

During the pandemic, system operators and utilities were in constant contact with federal regulatory and emergency management officials at the local, state, and federal levels.

- ✔ In the United States, RTOs/ISOs not only communicated with generation, transmission, and distribution utilities within their regions and coordinated with pipeline industry but also with other RTOs and ISOs, the industry body for the bulk electric system, the North

American Electric Corporation, the Electricity Subsector Coordinating Council, and the North American Transmission Forum. The industry also coordinated with health authorities to ensure that critical operations personnel had access to coronavirus testing.
- ✔ In Australia, the AEMO performed a leading role in the industry to ensure that Australian power systems continued to operate securely and reliably. The AEMO was in contact with federal and state governments as well as utilities and policy and regulatory bodies to mitigate the effects of the pandemic while managing the fastest energy transition in the world.
- ✔ In Europe, the TSOs of each member state coordinated with their respective ministry and national regulatory authority to implement measures and mitigations to ensure safety of the grid operation. Although decisions had been made at the national level, European TSOs continuously coordinated at the European Network of Transmission System Operators for Electricity level to share measures and common practices.
- ✔ In Brazil, ONS exchanged experiences with other operators, including the participation in global forums organized by the association of the Very Large Power Grid Operators (GO15), Center for Integrative Environment Research, and Electric Power Research Institute and had many interactions with local stakeholders.

COVID-19 affected the available workforce and the ability of utilities and system operators to respond to challenges. To ensure their employees' safety, system operators and utilities suspended travel and implemented a work-from-home policy for their employees, except for critical control room operators and other shift personnel. All stakeholder meetings were moved to teleconferences, with workplace attendance being restricted to critical personnel and vendors. More resilient communications technologies have been used to maintain connectivity, while adhering to cybersecurity protocols.

Looking Forward

In 2020, when the world faced a pandemic for the first time in nearly a century, there was little certainty on how this would affect us. Modern societies cannot function without electricity, and reliable operation of power systems was critical for continuation of modern life. System operators and utilities across the world embraced the challenges, reverting to their business-continuity plans, some of which were initially developed nearly a decade ago.

The pandemic taught system operators many lessons and introduced new ways of doing business. Looking back at how the pandemic evolved and how prepared system operators were to face its challenges, one may think that they went overboard, being prepared for every conceivable scenario. However, this is the function of a prudent system operator: to be prepared for the worst and hope for the best.

Some of these lessons have now become a part of daily operations and will remain as valuable practices. Promoting flexible resources and energy storages to guarantee reliable grid operation while meeting variable renewable production targets is key. With a higher occurrence of natural disasters from climate change as well as the pandemic—as the hydro scarcity in Brazil shows—system operators need to increase resiliency to extreme events and incorporate all system constraints on resource-adequacy procedures. The search for flexibility and resiliency from supply, demand, and transmission resources and the cost-efficient coordination of multiple interdependent infrastructures is fundamental to secure reliable supply while also efficiently integrating renewables. Unlocking such a future will need a more advanced market design and regulatory framework that allows the entrance of new technologies. Resilient and flexible grids can help us navigate pandemic and natural disasters.

Through dedication, out-of-the-box thinking, extraordinary efforts, and coordination, power grids have been operated securely and reliably during this pandemic, and system operators are now more prepared if such a disruptive event occurs again. System operators are more knowledgeable, resilient, and experienced. The reliable, resilient, and cost-effective delivery of electricity is necessary for society to cope with any crisis.

For Further Reading

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