Preserving Operational Continuity for Electric Utility Control Rooms During the COVID-19 Pandemic

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Abstract

Modelling of the COVID-19 pandemic shows control room operators at electric utilities will have high probability of being exposed and possibly infected. High absenteeism in operator teams, if not proactively managed, will reduce electric reliability and could cause blackouts. Reported COVID-19 cases used in a generalized logistic growth model indicate unmitigated spread in the U.S. could peak in the last week of April 2020. Alternatively, if mitigations are successful, the peak might be delayed until September or later. Utilities should plan for multiple scenarios. CDC guidelines should recommend asymptomatic testing of operators. When community infections are prevalent, operators should have priority for N95 masks and other personal protections. Monitoring and reporting of workforce health status to organizations such as the E-ISAC will be critically important during the COVID-19 pandemic. Medical personnel may be assigned to the most critical control facilities. Information sharing will enable better support to utilities from state, local, and federal governments. Modelling indicates that pandemic planning should be reexamined and updated by early April 2020.

KEYWORDS

Electric utility, control room, pandemic, COVID-19.

1 | INTRODUCTION

Electric utilities rely on a small number of highly trained operators for their control rooms. Inadequate staffing of control rooms combined with a sudden grid disturbance could cause system collapse. Experienced operators are essential for reliable grid operations, response to disturbances and, in the event of a blackout, system restoration. Reliable power for critical infrastructure and facilities delivering lifeline services, especially hospitals, is essential during the COVID-19 pandemic**.** A single control room team consisting of two dozen operators or fewer may be responsible for the electric power supplied to hundreds of hospitals. Operator health is vital.

If COVID-19 cases follow observed exponential growth rates for the United States and other industrialized nations, our modelling shows that active infections could sharply peak in the last week of April 2020. Alternatively, if mitigations result in 10% or even 5% daily growth rates, flatter epidemic curves could reach their peaks in June or September, respectively. Utilities should plan for a variety of COVID-19 scenarios.

Many utilities are already anticipating high infection rates in their local communities, continual exposure of their workforce, and disease clusters among control room operators. Pandemic plans may include long-term isolation of operators, cross-training, recall of retirees, assignment of operators to backup control rooms, and stockpiling of food, water, and fuel. When community infections are prevalent, control room operators should have priority for N95 masks and other protections. Public health officials may assign medical personnel to work on-site at control rooms.

The Centers for Disease Control should recommend asymptomatic COVID-19 testing of control room operators to prevent infection clusters in enclosed workspaces. Regular reporting of workforce status to information sharing organizations, such as the Electricity Information Sharing and Analysis Center (E-ISAC) of the North American Electric Reliability Corporation (NERC), will be critical in coordinating industry action. Information sharing will also allow state, local, and federal governments to better assist utilities in maintaining continuity of operations. On March 10, 2020, NERC requested its registered entities to report on the status of pandemic planning. [1]

2 | COVID-19 VIRUS

The COVID-19 virus, first detected in Wuhan, China, is rapidly spreading in industrialized nations dependent on reliable electricity. According to a model developed by the U.S. Centers for Disease Control and Prevention (CDC), COVID-19 could infect between 50% and 65% of the American population. [2] On March 10, 2020 Chancellor Angela Merkel informed her parliament that 60-70% of the German population could ultimately become infected with COVID-19. [3]

COVID-19 is transmitted by respiratory droplets, personal contact, and possibly by contaminated surfaces. The incubation period ranges from a mean of 5.1 days to an effective maximum of 14 days; some infections are asymptomatic [4]. According to the World Health Organization (WHO), “the median time from onset to clinical recovery for mild cases is approximately 2 weeks and is 3-6 weeks for patients with severe or critical disease.” [5] Eighty-one percent of COVID-19 cases have been reported to be mild (non-pneumonia and mild pneumonia). [6]

3 | CONTROL OF ELECTRIC GRIDS

The COVID-19 virus will require public health officials and other government leaders to think in new ways about the reliable supply of electricity to hospitals and other critical infrastructures. Among utility operations, control rooms are probably the most vulnerable to virus-related disruption. Within these rooms, highly specialized operators control the generation, transmission, and distribution of electricity 24 hours a day, seven days a week. Utilities with control rooms include those operating centralized generation facilities (including both individual plants and generation dispatch centers), transmission system operators, balancing authorities, distribution providers, and reliability coordinators.

Control room staffing per shift is surprisingly small, even at utilities with large generation plants and vast transmission systems. Modern generation plants may have two or three operators per shift. Transmission system operators and reliability coordinators who control power across multiple states typically have about five operators in the control room during a shift, but may have more during emergency operations. Small distribution providers such as municipals or cooperatives may have only one or two operators per shift but are critical for local electric reliability.

A single facility (and its backup location) can control the electric power for millions of consumers. Examples are PJM, California ISO, and New York ISO serving populations of 65 million, 32 million, and 19 million respectively. [7] [8] [9] The most critical control facilities have both primary and backup control rooms simultaneously staffed.

Grid operators are a minor percentage of utility workforces. Slack capacity for rotating shifts conducted 24 hours per day, seven days a week can be low if overtime is regularly used, especially at generation plants nearing their decommissioning dates. Because of the complexity of control room tasks and the importance of intimate knowledge of grid and plant operations under different conditions, rapid training and certification of replacement operators is infeasible. If absenteeism rates for operators were to be consistent with peak infection rates in the local community—or if a large proportion of operators stay home to care for family members—some workstations may be left empty or staffed with uncertified personnel.

4 | COVID-19 SCENARIOS

In the first stages of what ultimately becomes an epidemic (or pandemic), disease transmission is deceivingly low. The mathematics of exponential growth in a large population dictate a small number of cases in the early stage (compared with the total population), followed by large additions when the peak of infections is near. If mitigation measures do not significantly affect the growth rate, the trend for early infections can approximately indicate the time when peak cases will occur.

We used daily case numbers to model COVID-19 infections in the United States and four other industrialized nations: France, Germany, Italy, and the United Kingdom. We selected the generalized logistic growth model (LGM) that is suitable for simple modelling of epidemics. [10] We adapted LGM to a stepwise numeric method that works well in computerized spreadsheets:

$$C(d+1) = C(d) + C(d)r(1 - \frac{C(d)}{K}) \tag{1}$$

Where:

C = Cumulative number of cases
d = day number of period modeled
r = daily growth rate
K = maximum size of the epidemic

We set the value of K to be 50% of the total population for each country studied. We chose the value of 50% because it is the lower bound for a reported CDC infection scenario for the U.S. According a model developed by the COVID-19 Response Team at the Imperial College of London [6], another value for K could be 81% for the U.S. and UK populations.

We conservatively modeled the active number of cases by summing daily additions to cases (the rightmost term of equation 1) for the current day and prior 13 days, for a total of 14 days. This summation represents cases actively infected. We selected a period of 14 days because time from onset to clinical recovery for mild cases is approximately 2 weeks and most cases are mild. [4]

$$a = \sum_{d}^{d-13} C(d)r(1-\frac{C(d)}{K}) \tag{2}$$

Where:

a = active number of cases

For data on cumulative number of cases in the United States, we used the COVID-19 data collected by the Center for Systems Science and Engineering (CSSE) at Johns Hopkins University. [11] For data for France, Germany, Italy, and the UK, we used data collected by Worldometer. [12]

To determine the daily growth rate for infections, we performed a linear regression on the logarithmic values of the daily cumulative cases for the days March 1-15 (x=day number, y=log(C)). We performed an inverse logarithm on the x regression coefficient, subtracting 1 to find the daily growth rate. The r square values for the United States, France, Germany, Italy, and the United Kingdom were all 0.98 or above.

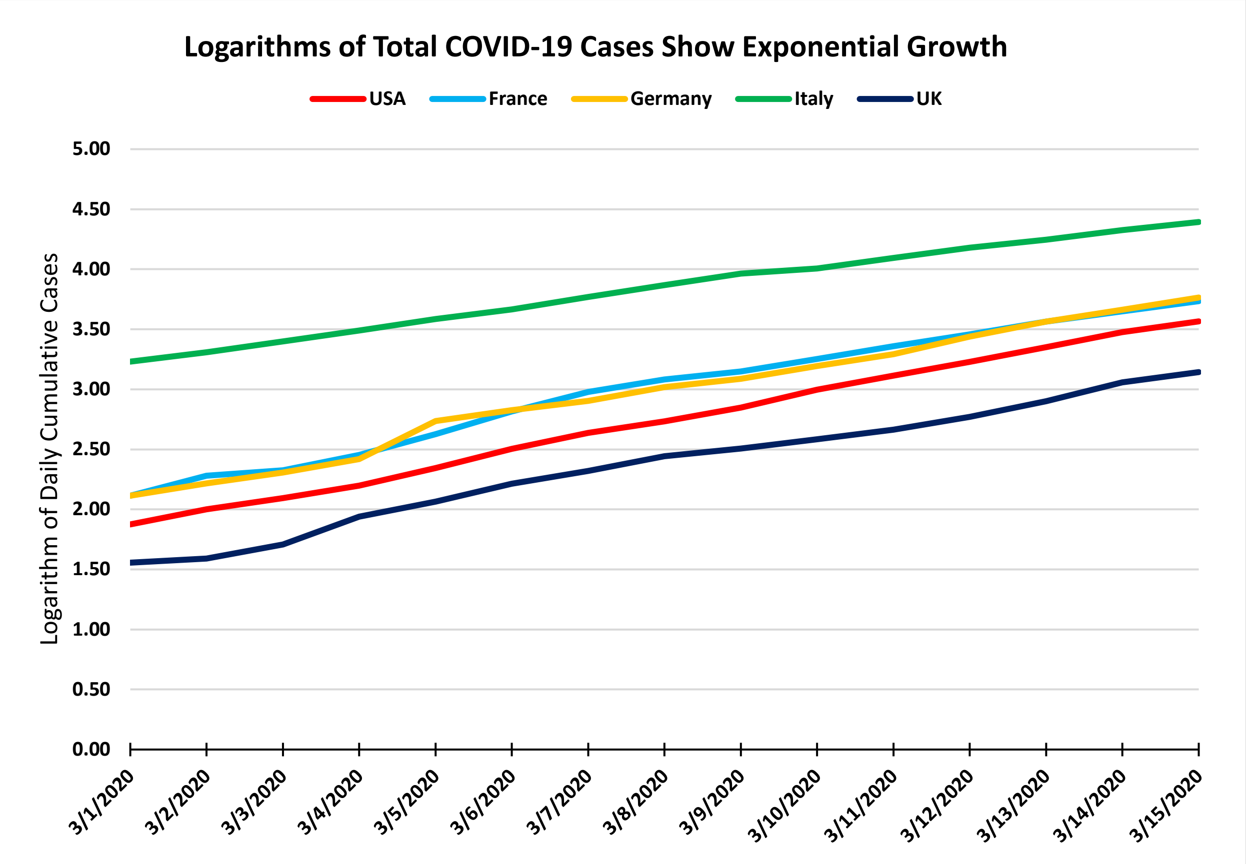

Figure 1. Logarithms of Cumulative COVID-19 Cases vs. Dates of Observation

Figure 1 shows plots of the logarithms of the cumulative number of reported cases for each country. The plots appear to be nearly straight lines, consistent with exponential growth. Italy, with a more advanced stage of COVID-19 spread, has its plot above the other four countries.

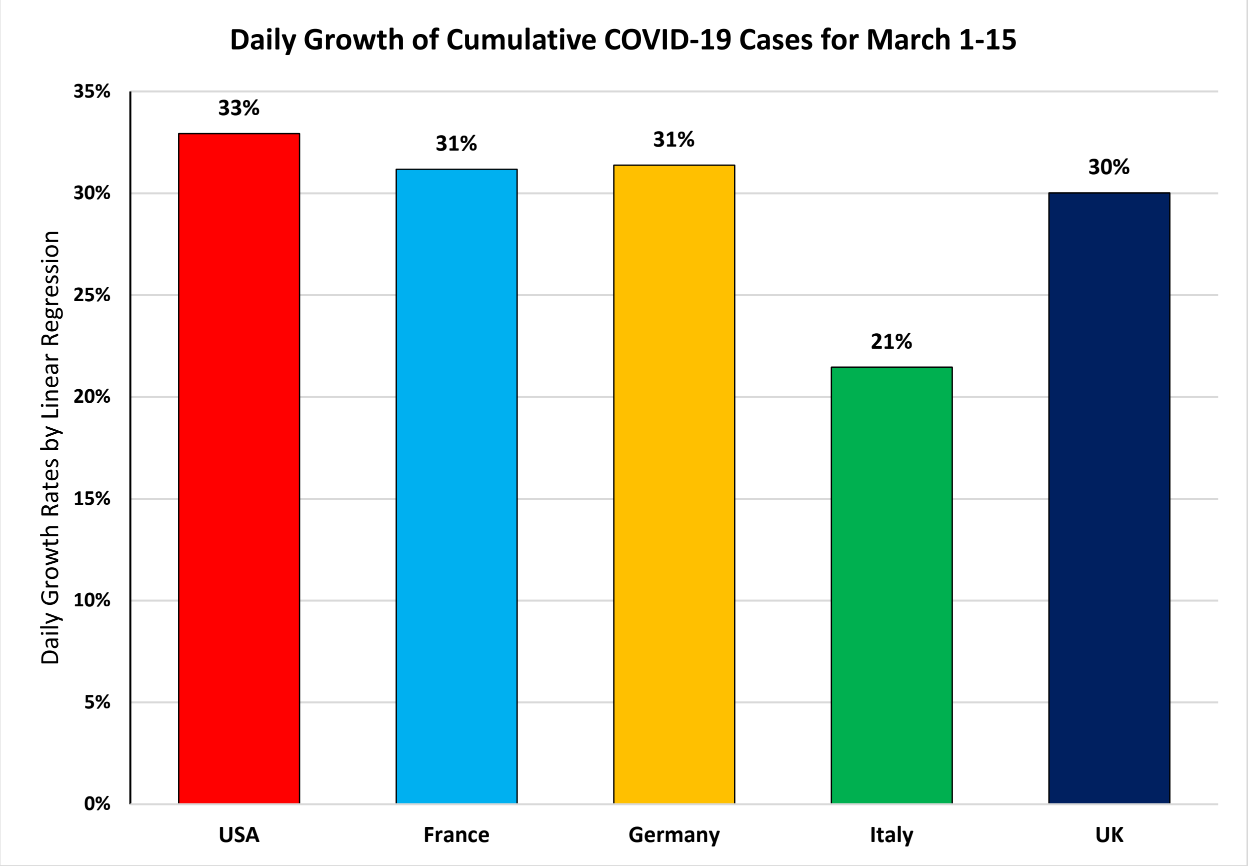

Figure 2. Daily Growth Rates with Minimal Mitigations

The growth rates in Figure 2 were used to model the epidemic curves in Figure 3 below. As Figure 2 shows, COVID-19 growth rates during the first half of March for most countries studied fall within a narrow range of 30% to 33% per day; this may be the intrinsic growth rate for COVID-19 in industrialized countries with mobile populations and dense urban centers. Alternatively, the observed growth rates may have been temporarily higher due to increased testing.

For the first half of March, Italy had a significantly lower growth rate than for other countries studied. The first lockdowns in Lombardy, Italy began on February 21, 2020. [13] On March 9, quarantine was expanded to all of Italy. [14] These mitigations may have lowered the observed growth rate for Italy below the intrinsic rate for COVID-19.

We do not expect the high daily growth rates in Figure 2 to continue when mitigations become more effective, nor do we believe that scenarios based on these growth rates are likely. Nonetheless, as we later demonstrate via modelling, even far lower growth rates can result in a significant proportion of the total population being actively infected by mid-to-late summer.

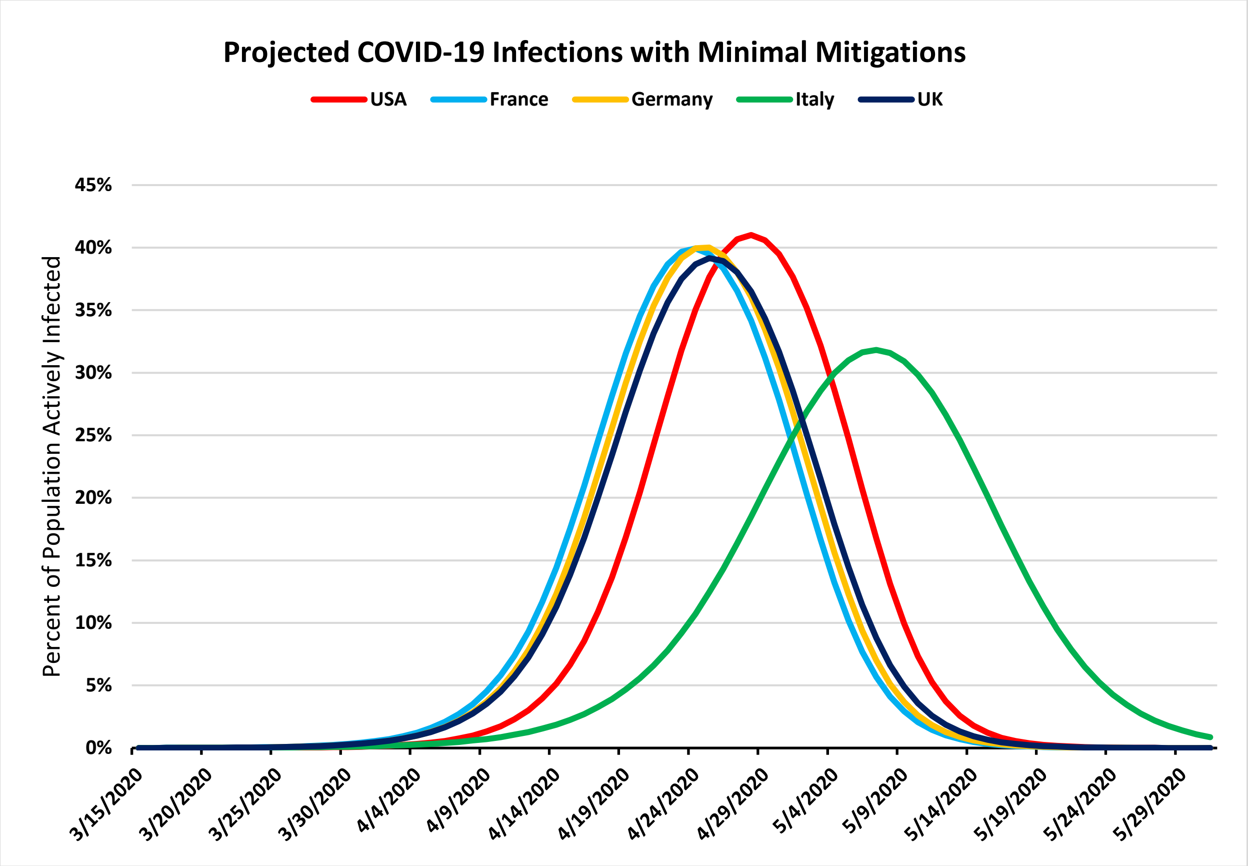

Figure 3. COVID-19 Epidemic Curves with Minimal Mitigations

Figure 3 shows modelling of five countries using daily growth rates determined from cases reported March 1-15, 2020. The total population for each country is used to calculate the percent of population actively infected. For all countries studied, the model projects that concurrent infection peaks in spring 2020. With stronger mitigations than other countries, Italy has apparently succeeded in "flattening the curve" and delaying its peak by several weeks.

The peak timeframes for our USA and UK scenarios are slightly before a more sophisticated model developed by the COVID-19 Response Team at the Imperial College of London. [15] The Imperial College team projected 81% of the U.S. and UK populations infected over the course of an unmitigated pandemic, with peak deaths occurring in the first days of June 2020. Because COVID-19 deaths lag onset of infections by 19 days, [16] our peak timing result of April 27 for the U.S. aligns within about three weeks of the Imperial College model.

On March 15, 2020, the U.S. administration announced, "The President's Coronavirus Guidelines for America—15 Days to Slow the Spread." [17]. To illustrate how mitigations such as those recommended can flatten the epidemic curve, we developed four scenarios for daily growth rates: 33% per day (approximating the U.S. growth rate in the first 15 days of March); 10% per day, 5% per day, and 1% per day. The experiences of China and South Korea show that testing, social distancing, and other mitigations can bring growth rates down to approximately 1%. The principal purpose of flattening the epidemic curve is to give the healthcare system additional time to prepare for a lower peak of patients and to develop treatments, but a flattened curve will also give electric utilities and other operators of critical infrastructure more time to prepare.

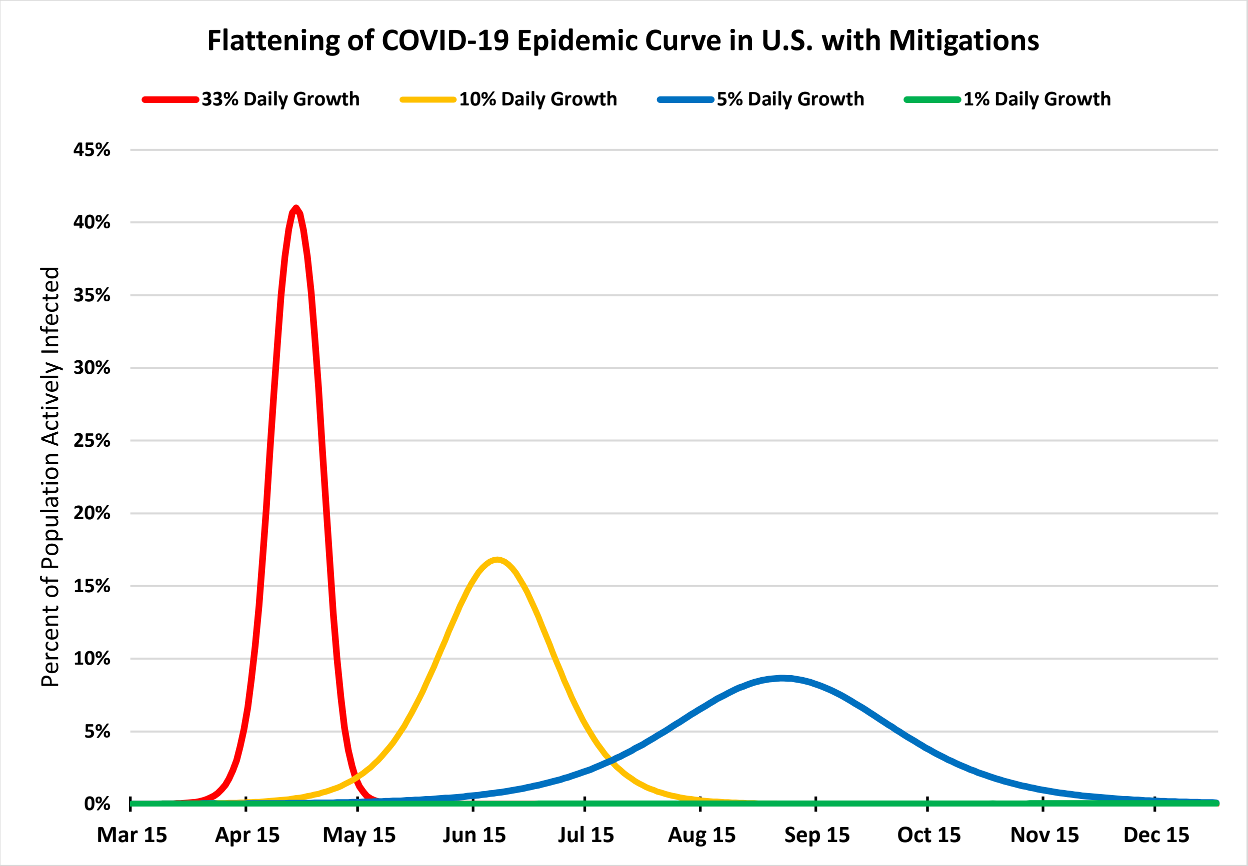

Figure 4. Flattening of COVID-19 Epidemic Curve in U.S. with Mitigations

Figure 4 compares four different growth rate scenarios for the U.S. If COVID-19 cases were to continue growth at the unlikely rate of 33% per day, our modelling shows a peak of 41% of the total population actively infected by the last week of April. At 10% daily growth, the modelled peak would occur in the last half of June at 17% of total population. At 5% daily growth, the modelled peak would occur in the first half of September at 9% of total population. At 1% daily

CAVEATS: Because of incomplete or inaccurate COVID-19 testing, the observed number of cases used to estimate exponential growth rates may not reflect the true number of infections. During the period March 1-15, 2020, increases in testing capability may have caused the number of reported cases to temporarily grow at a rate more than the intrinsic growth rate of COVID-19. Our model assumes virus spread within countries is homogenous—in reality "hot spots" develop and mitigations will be concentrated in these areas. The COVID-19 virus may mutate and change its behavior over time. The simple math in our model may not adequately project COVID-19 transmission. Despite these caveats, our model should provide operators of critical infrastructure actionable insights for a variety of COVID-19 scenarios.

growth, active infections in 2020 would not exceed 200,000. While 50% of the total population would ultimately be infected in all of these scenarios, utilities and the healthcare system would have more time to prepare under the mitigated scenarios. There is the possibility of secondary infection waves not modelled in our scenarios.

5 | PLANNING FOR CONTROL ROOM CONTINUITY

High levels of COVID-19 infections in local communities will increase the risk of disease clusters within teams of control room operators working rotating shifts in small rooms. Utilities will need to take measures that go far beyond the normal precautions of handwashing, sanitizing surfaces, avoiding personal contact, sending sick employees home, etc. Instead, utilities and government leaders must anticipate situations where rapidly increasing infections could result in lost grid control—and the risk of blackouts for millions of people. Government and community support for utility workforces and their families will be essential.

Using data from the U.S. Department of Labor [18], NERC Compliance Registry [19], and U.S. Energy Information Administration [20] [21], it is possible to estimate total team sizes across all shifts. Teams for U.S. power distributors and dispatchers average 22 members, teams for power plant operators average 19 members, and teams for nuclear power reactor operators average 106 members. Operators breathe air within enclosed windowless rooms and share workstations among rotating shifts. Shifts are typically 8-12 hours. When community infections are prevalent, there are high odds that one or more operators in a team will be infected and asymptomatically spreading the virus among colleagues. Surveillance testing of asymptomatic operators will be important for operational continuity and should be recommended under CDC guidelines.

An October 2010 study published in the Journal of Occupational and Environmental Medicine, “Factors Associated With the Ability and Willingness of Essential Workers to Report to Duty During a Pandemic,” surveyed first responders, department of health workers, and correctional facility employees. The study found that 49% of survey participants would be both willing and able to report to duty during a pandemic. This study also found that “Intention to wear respiratory protection during a pandemic” (N95 mask) was the most significant factor in being willing to report to duty. [22] While this survey did not specifically include control room operators, it is reasonable to expect that operators also put a premium on respiratory protection in deciding whether to report to duty during a pandemic.

A small number of control room operators are responsible for managing the electricity supply for millions of people. Control room operators have necessary interactions with executives, engineers, electricity market managers, technicians, and other utility workers. We therefore propose that when infections are prevalent in the community, and possibly prevalent in utility workers in the vicinity of the control room, operators should have high priority for N95 masks and other personal protective equipment, just as healthcare providers charged with individual care of patients have priority. Public health officials may assign healthcare personnel to work at control rooms..

Prediction of extreme absenteeism for utility employees during a pandemic is consistent with industry perspectives and prior research. In its February 2020 guide, “Electric Companies & Pandemic Planning,” the Edison Electric Institute says, “It is predicted that a large percentage of a company's employees (up to 40 percent) could be out sick, quarantined, or might stay home to care for sick family members." [23] The joint NERC/U.S. Department of Energy report, "High-Impact, Low-Frequency Event Risk to the North American Bulk Power System," has three scenarios for the peak week of a pandemic wave—Mild: 20% absenteeism; Moderate: 30% absenteeism; and Severe: 40% absenteeism or greater. [24] NERC's pandemic reference guide predicts up to 35% absenteeism. [25]

Three hypothetical case studies illustrate planning for control room continuity

Mitigations to flatten the epidemic curve will allow more time for cross-training and expansion of the pool of control room operators. Control room operators that have recently retired might be called back and retrained. If retirees have been infected, have recovered, and are now immune, their contributions could be especially valuable. Use of cross-trained but uncertified operators is another strategy. On March 18, 2020, the Federal Energy Regulatory Commission (FERC) and NERC issued a news release, "FERC, NERC Provide Industry Guidance to Ensure Grid Reliability Amid Potential Coronavirus Impacts." [26] In the news release, FERC and NERC announced a wavier to using NERC-certified personnel as system operators until December 31, 2020.

COVID-19 will force electric utilities to think differently—and carefully apply general government guidelines designed for nonessential industries. "The President's Coronavirus Guidelines for America" recommend "IF YOU FEEL SICK, stay home. Do not go to work." At the early stage of the COVID-19 pandemic, this advice could keep workforces at control rooms healthy. At the COVID-19 peak, exceptions – with the proper precautions – may be necessary.

Case Study for Big West Reliability

Big West Reliability is the reliability coordinator for the United States from the Rocky Mountains to the Pacific Coast. Big West operates two control rooms, one in Utah and the other in Washington State. Both control rooms are fully staffed and can perform as either primary or secondary. The on-duty operators for each room number five and the entire operator staff is 50.

Because Washington State was the epicenter of a COVID-19 outbreak, management made the decision to lockdown this facility early on. Fifteen out of twenty-five operators there volunteered to shelter in place for the pandemic duration.

The Washington facility is in a shared commercial office building. Regular asymptomatic testing revealed that three of the operators contracted COVID-19. It is believed that the common building ventilation system communicated the virus from an adjacent company to the control room. Public health officials shut down all other tenants in the building.

Management determined that six healthy operators should remain in the Washington control room 24/7 with the other healthy volunteers self-quarantining at home. This facility was designated as secondary, with the primary being in Utah.

Regular asymptomatic testing at the Washington control room showed that 8 out of 15 operators ultimately contracted COVID-19. As operators living in the control room tested positive, they were sent home or hospitalized. Healthy operators held in reserve and living at home took their places.

The Utah control room operated as primary through the duration of the pandemic. Three months into the pandemic, it was called upon to coordinate restoration operations for a cascading outage affecting the states of Arizona and California. Asymptomatic testing of the Utah operators found no infections while their control room was the primary.

Transmission system operators must work in control rooms with prerequisite communications, energy management systems (EMS), geographic information systems (GIS), and a multitude of tools that are only available in utility facilities (or fully functional backup control centers). Working remotely from home is not a viable possibility for most system operators. However, there are certain support functions that may be provided from remote locations. For example, engineers might conduct system studies. Remote access risks cybersecurity.

When the COVID-19 peak hits, continuous isolation of healthy control room operators ("sheltering in place") could be essential for maintaining electric grid reliability. This would require volunteers to work, sleep, and eat at their facilities until the pandemic wave subsides. Sleeping cots and supplies of food, water, and medications should be stockpiled as soon as possible, before the peak. Isolation from local communities may sound radical, but willing and critically important control room operators can provide greater security for their friends and families by isolating themselves at work than by living at home. Utilities are already planning some of these shelter-in place precautions. [27]

Case Study for Mid-Atlantic ISO

Mid-Atlantic ISO serves as a reliability coordinator and transmission system operator for five states along the eastern seaboard of the United States. Mid-Atlantic operates day-ahead and real-time electricity markets for these states. The primary control room is in the basement of the corporate headquarters. The secondary is in a converted underground bunker about 50 miles from the primary.

Because the market-making function is in the same facility as the primary control room, and because the office space for market-making economists shares a ventilation system with the control room, management at Mid-Atlantic decided to suspend its electricity market. FERC temporarily granted Reliability Must Run tariffs for all major generation plants within the Mid-Atlantic service area.

With only essential personnel reporting for duty at the corporate headquarters, the primary control room was kept operating with controllers living at home. Public health officials approved regular asymptomatic testing for all employees working at corporate headquarters. As employees tested positive, they were directed to self-isolate at home.

For the secondary control room in the bunker, volunteer operators agreed to shelter in place for the duration of the pandemic. Operators ate Meals Ready To Eat (MRE) and food prepared on-site. A filled fuel truck was parked next to the tank for the backup diesel generator. No operators for the secondary control room tested positive.

Both primary and secondary control room operators spent much time coordinating Reliability Must Run dispatch for generation plants accustomed to optional participation in the electricity market. For the first wave of the pandemic, no significant load was lost in the Mid-Atlantic ISO.

At an epidemic peak with a third or more of the total population infected, the societal risk of wide-area blackout from short staffing in control rooms may exceed the risk of operators working sick. For example, if 40% of a facility's control room operators are concurrently infected, and 80% of those infected with mild symptoms are willing to work sick, they might be assigned to work at a secondary control room (assuming that the backup location can be physically isolated from the uninfected workforce). If most of a critical facility's operators become infected, and those that are asymptomatic or have mild symptoms are willing and able to work, utility executives, emergency managers, and public health officials may designate the facility as having "Working While Sick" status. The minority of uninfected workers could be kept in reserve by isolating at work or home. Use of infected but recovered workers could be key.

Case Study for Riverview Generation Station

Riverview Generation Station, a 1.8 gigawatt dual-fuel plant (oil and gas-fired), supplies 20% of the electricity for a major metro area with population of 5 million. The station should have a full staff of 24 operators, but with the plant expected to decommission in two years, only 17 operators remain. Operators typically work 16-24 hours per week of overtime. Operating procedures for the aging plant are poorly documented, with much information in operators' heads.

System studies show that Riverview is essential to prevent rolling blackouts during peak load conditions. The plant also supplies reactive power, primary frequency response, and spinning reserves. Recognizing its importance for grid reliability, FERC had set a Reliability Must Run tariff for the Riverview plant well before the pandemic.

When COVID-19 infections hit 2% of the metro area's population, the plant was placed on lockdown, with nine operators volunteering to shelter in place for the duration. A retired operator in the local area agreed to return to duty.

At a 5% area rate of infection, asymptomatic testing indicated that nine out of ten operators had contracted COVID-19. Contaminated cardboard on a take-out pizza box may have caused the disease cluster. The utility shared the workforce status of the plant's operators with the E-ISAC.

A physician assistant (PA) assigned to work at the plant examined all ten of the operators and determined that two should self-isolate at home—the healthy operator and an infected operator who was 62 years old with hypertension. The other eight operators had no symptoms and agreed to remain on duty.

Ten days after testing confirmed COVID-19 infection, an operator developed pneumonia, as determined by the on-site PA, and was hospitalized. The remaining seven original volunteers recovered from mild COVID-19 while working.

Another five operators had contracted the virus at home and recovered; after outreach by the utility's human resources department, they decided to return to work at the plant. The reconstituted team reliably operated the plant until the pandemic was mitigated in the metro area and additional operators were trained.

The concept of designating a control room or entire generation plant as having "Working While Sick" status may be met with scepticism by medical doctors, corporate attorneys, and public health professionals. Because urban areas and their hospitals are commonly served by large generation plants and critically important control rooms, difficult decisions on individual medical care versus reliability of electricity will need to be made—using plans that should be made before peak infections hit. Utilities should determine which facilities are short-staffed and using overtime. Medical personnel should determine which operators have underlying health conditions that might prevent them from working with mild COVID-19.

If employees of local fuel distributors are home sick (consistent with government guidelines), the service level agreement negotiated by the utility's legal department will not ensure resupply. Topping off the tanks for backup diesel generators—and possibly parking filled fuel trailers near the generators—are prudent measures. Diesel fuel stored longer than six months will have degraded and will need replacement or "fuel polishing."

Utility workers—and especially control room operators—may need government issuance of documentation to allow them to pass through quarantine checkpoints.

The above observations and suggestions are not exhaustive—surely utility managers and systems operators are thinking of a variety of ways to maintain continuity of control room operations. Many utilities and grid operators, including reliability coordinators and large transmission system operators, recognize the importance of business continuity and pandemic planning as discussed in this paper. [28] It is important that governmental agencies, such as the U.S. Public Health Service, U.S. Centers for Disease Control, Federal Emergency Management Agency, state emergency managers, and local public health officials understand these plans and the critical importance of control room operators to the reliable supply of electricity.

Smaller utilities and independent power producers would benefit from sharing in insights from pandemic planning by the Electric Subsector Coordinating Council and NERC. On March 10, 2020, the Electric Subsector Coordinating Council released a resource guide, “Assessing and Mitigating the Novel Coronavirus (COVID-19).” [29] On March 10, 2020, NERC released a Level 2 alert, “Coronavirus Disease (COVID-19) Pandemic Contingency Planning.” [1]. The alert requested all entities registered with NERC to respond to a six-question survey on pandemic planning by March 20.

6 | MONITORING CONTROL ROOM WORKFORCES

Control room operators at electric utilities enable reliable functioning of all other infrastructures, including the healthcare system. Monitoring operator health status—including COVID-19 infection rates, absenteeism, and recoveries—will be key during the pandemic. Again, the CDC should consider modifying its guidelines to permit asymptomatic testing of the moderate numbers of U.S. power distributors and dispatchers (11,700), power plant operators (34,900), and nuclear power reactor operators (6,400). [18] If asymptomatic celebrities can be tested—including eight entire NBA teams—then critical utility workers can be tested, too. [30]

The 2010 joint NERC and DOE report “High-Impact, Low-Frequency Event Risk to the North American Bulk Power System” had this Proposal for Action: [24]

> *NERC, the U.S. DOE, and appropriate government authorities in Canada should identify the kinds of information needed from the sector to effectively monitor critical workforce levels across the electric sector during a pandemic. A collaborative group of government and electric sector representatives should develop plans and procedures to efficiently meet information needs while limiting the data collection requirements where possible. This group should also develop mechanisms to share this information across the sector.*

Within North America, the tasks in the NERC/DOE Proposal for Action are well-suited to the existing capabilities of the E-ISAC. The E-ISAC can serve as a conduit for industry coordination and communication of workforce status to government authorities. When federal, state, and local governments understand the critical importance and workforce status of control room operators and other utility employees, they will be better able to make decisions and tailor emergency orders.

7 | APPLICATION TO OTHER CRITICAL INFRASTUCTURES

Other critical infrastructures have control rooms that are staffed 24/7 in windowless enclosed spaces. These infrastructures include telecommunications, natural gas pipelines, water and wastewater, railroads, mass transit systems, oil refineries, chemical plants, air traffic control, and others. In each, there is potential for cross-infection and high absenteeism within small teams of operators. The timing and magnitude of COVID-19 hazards, operational considerations, and imperatives for pandemic planning presented in this article also apply to these infrastructures.

8 | CONCLUSIONS AND RECOMMENDATIONS

Models from multiple researchers project widespread COVID-19 infections in coming months. Absenteeism among control room operators could impact electric grid reliability and result in blackouts for hospitals and surrounding communities. Because of the critical societal role of control room operators and high risk of cross-infection within operator teams working in enclosed spaces for long shifts, asymptomatic testing should be recommended in CDC guidelines. Operators need priority for N95 masks and on-site medical personnel. Sharing of workforce status with the E-ISAC would coordinate industry efforts and speed government support during emergencies. To be prepared for a worst-case scenario, utilities need to complete pandemic planning and establish processes for workforce information sharing by early April 2020.

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REFERENCES

[1] North American Electric Reliability Corporation, *Coronavirus Disease (COVID-19) Pandemic Contingency Planning,* 2020.

[2] S. Fink, “Worst-Case Estimates for U.S. Coronavirus Deaths,” *New York Times,* 17 March 2020.

[3] R. Schuler, “60 bis 70 Prozent in Deutschland werden sich infizieren,” *Bild,* 10 March 2020.

[4] S. A. Lauer, K. Grantz and Q. Bi, “The Incubation Period of Coronavirus Disease 2019 (COVID-19) From Publicly Reported Confirmed Cases: Estimation and Application,” *Ann Intern Med.,* 2020.

[5] World Health Organization, “Report of the WHO-China Joint Mission on Coronavirus Disease 2019 (COVID-19),” 2020. [Online].

[6] Z. Wu and J. McGoogan, “Characteristics of and Important Lessons From the Coronavirus Disease 2019 (COVID-19) Outbreak in China,” *JAMA,* 24 February 2020.

[7] PJM, *PJM Statistics,* 2019.

[8] California ISO, *Understanding the ISO.*

[9] U.S. Census Bureau, *2019 National and State Population Estimates.*

[10] K. Wu, D. Darcet, W. Qian and S. Didier, “Generalized logistic growth modeling of the COVID-19 outbreak in 29 provinces in China and in the rest of the world,” *ArZiv.org,* 12 March 2020.

[11] Center for Systems Science and Engineering (CSSE) at Johns Hopkins University, “ CSSEGISandData/COVID-19,” [Online]. Available: https://github.com/CSSEGISandData/COVID-19/tree/master/csse_covid_19_data.

[12] Worldometer, “Confirmed Cases and Deaths by Country, Territory, or Conveyance,” [Online]. Available: https://www.worldometers.info/coronavirus/#countries.

[13] L. Bruno and W. Nicole, “Italy reports 1st virus death, cases more than quadruple,” *Associated Press,* 21 February 2020.

[14] C. Barry and A. Clanni, “Italian premier locks down entire country to stop virus,” *ABC News,* 9 March 2020.

[15] Imperial College COVID-19 Response Team, “Impact of non-pharmaceutical interventions (NPIs) to reduce COVID-19 mortality and healthcare demand,” 16 March 2020.

[16] F. Zhou, T. Yu, R. Du and G. Fan, “Clinical course and risk factors for mortality of adult inpatients with COVID-19 in Wuhan, China: a retrospective cohort study,” *The Lancet,* 11 March 2020.

[17] The U.S. White House, “The President’s Coronavirus Guidelines for America,” 15 March 2020. [Online].

[18] U.S. Bureau of Labor Statistics, “Power Plant Operators, Distributors, and Dispatchers,” 2018. [Online]. Available: https://www.bls.gov/ooh/production/power-plant-operators-distributors-and-dispatchers.htm#tab-3.

[19] North American Electric Reliability Corporation, “Organization Registration and Organization Certification,” [Online]. Available: https://www.nerc.com/pa/comp/Pages/Registration.aspx. [Accessed 2019].

[20] U.S. Energy Information Administration, “Nuclear explained,” 2018. [Online]. Available: https://www.eia.gov/energyexplained/nuclear/us-nuclear-industry.php.

[21] U.S. Energy Information Administration, “Form EIA-860 detailed data with previous form data,” 2016. [Online].

[22] R. R. M. Gershon, L. Magda and K. Qureshi, “Factors Associated With the Ability and Willingness of Essential Workers to Report to Duty During a Pandemic,” *Journal of Occupational and Environmental Medicine,* vol. 52, no. 10, 2010.

[23] Edison Electric Institute, “Electric Companies & Pandemic Planning,” Feburary 2020. [Online].

[24] North American Electric Reliability Corporation and U.S. Department of Energy, “High-Impact, Low-Frequency Event Risk to the North American Bulk Power System,” 2010.

[25] North American Electric Reliability Council, “Electricity Sector Influenza Pandemic Planning, Preparation, and Response Reference Guide,” [Online]. Available: https://www.nerc.com/comm/CIPC_Security_Guidelines_DL/NAERC200701.pdf.

[26] Federal Energy Regulatory Commission and North American Electric Reliability Corporation, *FERC, NERC Provide Industry Guidance to Ensure Grid Reliability Amid Potential Coronavirus Impacts,* 2020.

[27] V. Volcovici and S. DiSavino, “U.S. power industry may ask key employees to live at work if coronavirus worsens,” *Reuters,* 20 March 2020.

[28] R. Phelps, J. McMenamin and D. Kieffer, “The Microbiological Threat to the National Power Grid,” McGuireWoods LLP, 2007.

[29] Electricity Subsector Coordinating Council, *Assessing and Mitigating the Novel Coronavirus (COVID-19),* 2020.

[30] M. Twohey, S. Elder and M. Stein, “Need a Coronavirus Test? Being Rich and Famous May Help,” *New York Times,* 18 March 2020.