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The Natural Gas Grid Needs Better Monitoring

Hundreds of times each year the natural gas pipeline system fails, shutting down electric power plants, but there is no national system to record these events and help us improve reliability.

We are familiar with cascading electric grid outages such as the September 8, 2011, blackout that hit San Diego at rush hour, and the August 14, 2003, blackout that essentially shut down the Northeast. Less familiar are failures in the US natural gas pipeline system. But they occur.

Fuel-starvation outages at US gas power plants happened at an average rate of a thousand events per year and affected one in five plants between January 2012 and April 2016, according to the North American Electric Reliability Corporation (NERC). Sometimes, in very cold weather, many gas plants are starved of fuel at the same time.

Because data on the reliability of the natural gas pipeline system is almost impossible for anyone to find, our team spent a year combing through the reports filed by power plants—not pipelines—to count these outages. To our knowledge this is the first time anyone has done so.

Unlike electric power generator failures, gas pipeline outages are either not recorded or not available without a Freedom of Information Act request in most states. But disruptions in the natural gas system can have serious consequences, particularly for electric power generation.

For power system reliability, it is important to know how often, where, and why pipeline failures occur so that power plant operators can be better prepared for gas interruptions. Storing backup gas supplies at the generator site is impractical because the required tank farm to hold compressed gas for just one day's power plant operation would increase the plant's footprint by at least 10%, and that doesn't even consider the ancillary equipment required to support the gas storage. Liquefied natural gas storage, even for a few hours' worth of plant operation, is very expensive. And underground storage at the plant is equally impractical for most plants. Another option to protect against gas supply interruptions is to design in fuel-switching capability that can easily substitute oil for gas. But only one-quarter of gas power plants have the ability to switch to oil without halting operation, and about half of those plants can operate for only a short time with oil because of on-site oil storage limitations.

The remaining three-quarters of plants that do not have fuel-switching abilities are tied to the real-time reliability of the natural gas pipeline transportation network. When emergency situations arise on the natural gas grid, pipeline operators turn to a load-shedding protocol that outlines the order in which customers will have their gas supply turned

off. The shedding of load restores operational stability to the gas grid in situations of high stress.

On the other side of the gas meter, however, as pipeline operators carry out their load-shedding procedure to restore stability to the gas grid, power plants might have to shut down, forcing other plants to increase their electric output. If the generation shifting creates a large enough stress on the electricity network, other power plants sometimes fail, creating further instability on the electric grid.

Under current reporting requirements it is possible to obtain only an incomplete picture of the frequency of these kinds of interdependent natural gas/electricity infrastructure failures. Recent lessons in interdependency between the gas and electric grids (see Box 1) are a call to action to better align data availability of both grids' operational characteristics. This is not a new message. In 2013, NERC released phase II of its special reliability assessment report titled "Accommodating an Increased Dependence on Natural Gas for Electric Power." It identified a lack of "compiled statistical data on gas system outages" that would be equivalent to the databases that NERC has complied in its Generating Availability Data System (GADS). NERC called on the natural gas transmission sector to work with it to establish a central pipeline outage database that would make it possible to conduct reliability analyses of the dual-grid system.

NERC's message has been heard in the academic community. Currently, academic teams across the country, ours included, are exploring the issues presented in the special reliability assessment. But nothing has been done in the ensuing years to fix the data misalignment. We just don't know how vulnerable the nation is, and we don't know where to apply management attention to reduce the vulnerabilities.

To address this problem we explore the current federal reporting standards relevant to quantitative analysis of the reliability of the dual-grid system as they exist today and recommend a path of development for the central database recommended by NERC.

A tale of two thresholds

For electric generators, the GADS Data Reporting Instructions outline specific, numerical thresholds for mandatory reporting. Events are to be reported that cause any power plant with nameplate capacity of 20 megawatts (MW) or greater (the vast majority of all plants) to fail at start-up, to be completely unavailable unexpectedly, or to be unable to provide the full amount of power the plant promised to the grid. Power plant "derating" reports are mandatory for all events causing the equivalent of 2% or more of the power plant's net maximum capacity to be unavailable for 30 minutes or more. A cause identification code is included with every power plant failure report. Between January 2012 and April 2016, more than 1,000 failure events per year were reported by power plant operators claiming lack of fuel from the gas pipeline network. The data from these reports are confidential, but aggregate data that are fine for measuring overall reliability have been published.

Reliability events for gas pipelines, on the other hand, are reported to various entities, but with reporting thresholds that vary by jurisdiction. The Federal Energy Regulatory Commission (FERC) has jurisdiction over operation of interstate pipelines; the Pipeline and Hazardous Materials Safety Administration (PHMSA) for interstate and intrastate pipeline safety; and the state Public Utility Commissions for intrastate pipeline networks—mostly for local distribution companies. According to mapping data provided by the Energy Information Administration, roughly 60% of natural gas power plants with capacity of 20 MW or larger are within five miles of an interstate pipeline. The remaining 40% are probably fueled by smaller, intrastate pipeline systems. Therefore, it is important that reliability data be available for both interstate and intrastate pipelines. Because the US natural gas grid does not have a central reliability organization, compiled data sources that are sufficient to model interdependencies between the gas and electric systems are hard to find.

One promising data source that could meet the needed criteria arises from a FERC rule that requires "emergency transaction" reports (Form 588) from pipeline operators. An emergency transaction occurs as a result of "any situation in which an actual or expected shortage of gas supply would require an interstate pipeline company, intrastate pipeline, local distribution company, or [pipeline that is not under FERC jurisdiction due to stipulations in the Natural Gas Act] to curtail deliveries of gas or provide less than the projected level of service to any customer." The reporting requirements of the regulation could be read to require transaction records for partial as well as complete gas curtailment events.

But this is only one way to read the rule. By our interpretation of the definition of an emergency transaction, the FERC-588 reports should capture the data that are needed to study reliability, but they don't. The filings under FERC-588 and other gas pipeline emergency reports are available on FERC's eLibrary website. Searching the eLibrary for

emergency filings using the keywords "interrupt," "outage," or "curtail" produces 32 results from 17 unique pipeline events between 2012 and 2015. Most of the events were for gas flow diversions to avoid pipe segments taken out of service for maintenance. In these cases, the emergency transactions were brokered to avoid gas interruptions to customers.

However, despite the fact that multiple delivery failures have occurred, only one report over the period details a service interruption that could have affected a power plant located on the pipeline. Thus, the FERC-588 data are no help in understanding the reliability of the natural gas system.

In March 2011, a gas gathering line in the Gulf of Mexico was struck by a dredging operation and knocked out of service for over 250 days. In January 2016, a 30-inch steel transmission pipeline in the Southwest ignited due to a rupture of the pipe material. The explosion caused service to be interrupted on the pipeline for 35 days as repairs were made. In July 2016, while crews at a western gas distribution utility worked to fix a leaky valve, they accidentally struck a 4-inch plastic main, causing the gas to ignite. Extensive system damage occurred, 30 people were evacuated, and gas service was shut down for a day.

Not one of those events is in the FERC data.

Since the FERC data are not very informative, the most comprehensive, easily accessible, centralized source that captures both inter- and intrastate pipeline data is the PHMSA Natural Gas Distribution, Transmission & Gathering Accident and Incident Database. The one service interruption in the FERC data is also captured by the PHMSA database. These data are filed by the pipeline operators and have been gathered since 1970. The data are compiled and catalogued with a description of each pipeline incident and its subsequent root-cause investigation. PHMSA makes these data available publicly on its website. The thresholds that trigger a mandatory report to PHMSA include an event that results in a release of gas or hazardous liquid from the pipeline as well as at least one of the following: a death, or personal injury necessitating in-patient hospitalization; estimated property damage of $50,000 or more … excluding the cost of gas lost; or unintentional estimated gas loss of three million cubic feet or more.

The regulatory language also calls for reporting any event that is "significant in the judgment of the operator, even though it did not meet the [previous] criteria … of this definition." As PHMSA is a safety-centered organization, the thresholds focus on safety-related metrics; however, some of the fields on the forms that pipelines operators and investigators submit to PHMSA after an incident capture important reliability metrics such as the system component affected, shutdown time, and the primary cause.

An analysis of the 673 PHMSA accident and incident reports for distribution, gathering, and transmission pipelines between 2012 and 2015 shows that approximately 80% of reports met at least one of the automatic report conditions, and 20% did not. The 131 reports that did not meet the conditions can be viewed as those "judged significant" by the pipeline operator. But as mentioned in Box 1, the serious events at Aliso Canyon and in New Mexico are not found in the data available on PHMSA's website. This leads us to wonder how many other significant events are missing from these data, or even what a significant event is judged to be.

Unlike electric power generator failures, gas pipeline outages are either not recorded or not available without a Freedom of Information Act request in most states.

The only way we can effectively study interdependent reliability is if the standards for reporting pipeline outages and power plant failures are sufficiently equivalent. In comparing the GADS and PHMSA reporting thresholds, it is evident that the language for reporting outage events at power plants is far more stringent than for gas pipeline outages. Again, this is probably because PHMSA's mission is safety, and there is no central reliability organization for the gas network.

A 460 MW combined-cycle natural gas power plant (the median size of such plants) consumes the equivalent of almost three million cubic feet of natural gas per hour at normal atmospheric pressure. That means that an unintentional release of three million cubic feet of gas (the threshold for making a PHMSA report) represents just over one hour of the power plant's full operation. For electricity-side reporting at a power plant of this size, a complete power plant outage of any duration or a derating event equivalent to just 2% of the plant's capacity for 30 minutes or more must be reported. That is the equivalent of 30,000 cubic feet of natural gas at atmospheric pressure. The event would have to be 100 times as

Box 1. GAS-ELECTRIC INTERDEPENDENCE

In February 2011, an extreme weather event hit the Southwestern United States, chilling local temperatures to as low as 30 degrees below zero. The temperature dropped so low in places that water vapor at natural gas wellheads froze, restricting flow from production areas to the residents of the area. Simultaneously, regional electric power plants failed to keep up with demand due to inadequate planning for the unexpected cold weather. The Electric Reliability Council of Texas reported that over the first four days of February, 152 individual generator units at 60 power plants in the state didn't provide the electricity they promised, triggering the initiation of rolling blackouts. More than 75% of the units reporting forced outages relied directly on natural gas as their primary fuel source. On the first night of the event, more than 8,000 megawatts of power generation unexpectedly dropped offline; that was 12% of the entire installed capacity of the electricity grid.

Further compounding the problem, a segment of the regional pipeline system that shipped natural gas from unfrozen production wells in Texas to markets in New Mexico and farther west relied on Texas grid electricity to power its compressor stations. When the rolling blackouts started, the electric compressor stations shut down, and the gas pressure in the regional pipeline system fell, starving customers in New Mexico of natural gas for heating. When all was said and done, 28,000 natural gas customers in New Mexico were forced to find other ways to protect themselves and their families from the bitter cold.

When large natural gas storage facilities fail, they wreak havoc on fuel supply stability for power generators. In October 2015, a 7-inch injection well casing at the Aliso Canyon natural gas storage field in Southern California failed, creating the largest natural gas leak in US history. Nearly four months passed as the operator and emergency responders worked to contain the leak.

large to trigger a PHMSA report. But power plants are fueled by high-pressure natural gas supplies, which means that a 2% derating for 30 minutes represents roughly only 600 cubic feet of gas consumption at pressure, 5,000 times less than the PHMSA threshold.

This example helps illustrate why we think it is wrong that the only numerical, operational threshold for automatic gas pipeline incident reporting to the most comprehensive database is the volume of gas released. Gas volume released, although important for financial, environmental, and safety reasons, is inadequate for system reliability analysis. Fluctuations in system pressure, or volumetric flow rates, are the important system variables for gas system reliability as they characterize a pipeline company's ability to serve loads. Furthermore, as the language specifies, the explicit thresholds trigger a mandatory report only for incidents that occur simultaneously with an unintentional release of gas or hazardous liquid. Important reliability events without releases of gas from pipelines, such as reductions in operating pressure of the gas system, are left out of these explicit definitions. In the absence of more encompassing data, reliability analysts working with the PHMSA data are left to depend on the events that the operator judges to be "significant."

Perhaps more appropriate data are collected through other means and have been used internally for reliability assessments of the gas grid. We have not seen any reasons to believe this is the case, but even if it is, an internal assessment isn't as good as having an open community reliability analysis, which would provide regulators and the many stakeholders of the gas grid with valuable information while also reducing the administrative burden of completing these analyses in-house. State agencies, academic institutions, trade organizations, businesses using gas for emergency back-up generators, and large natural gas consumers such as power plants should be provided access to pipeline reliability data that are not deemed a threat to national security. For power plants, these data are crucial for both siting of new plants and contracting for gas supply. Access to data that can capture events on interstate and intrastate pipelines with the potential to affect the bulk power network should be provided outside the walls of government so experts across the country can analyze the reliability of the interdependent gas and electric grid systems on a level playing field.

First steps in the right direction

In September 2013, the National Association of Pipeline Safety Representatives (NAPSR), an organization with ties to the National Association of Regulatory Utility Commissioners, released a document titled "Compendium of State Pipeline Safety Requirements & Initiatives Providing Increased Public Safety Levels compared to Code of Federal

Regulations." In the report, NAPSR noted that state regulators had 308 enhanced reporting initiatives in place that would require pipeline operators to report safety conditions above and beyond those required by federal standards. They also reported that 33 states had various types of enhanced reporting standards with specific reference to the regulation underlying the PHMSA reporting thresholds. These enhanced standards included lowered property damage thresholds, outpatient injury reports, and other modifications to the FERC regulatory language.

Some important initiatives identified by NAPSR require pipeline operators to report outages affecting a specific number of customers, outages of a specific duration, or complaints of gas delivery pressure issues. At the time that the compendium was released, 20 states had one of these categorical reporting standards in place.

The problem is that each of these 20 states has its own reporting thresholds with varying stringency. For instance, Pennsylvania requires reports of all gas outages affecting the lesser of 2,500 customers or 5% of total system customers. Florida requires reports of outages affecting the lesser of 500 customers or 10% of total gas meters on the pipeline network. Washington requires reports of outages affecting more than 25 customers. Wyoming requires reports of all service interruptions of any size.

The state reports appear to be a step toward solving one piece of the reliability puzzle. But only three states—New Hampshire, Rhode Island, and Washington—were listed by NAPSR as having a reporting requirement for system pressure issues. As discussed in Box 2, system pressure fluctuations without a complete gas outage can shut down gas turbines. One state, Maine, requires reports of all gas interruptions longer than a half hour that affect other utilities' critical facilities.

Data accessibility is also state-specific. Some states, such as Wyoming and Pennsylvania, make the records they collected publicly available on their state information portal websites (if you know what search terms to use to find these data). In other states, the data from the records are referenced only as footnotes in annual pipeline safety reports or are simply unavailable, requiring a Freedom of Information Act request to access the records.

A path forward

To properly manage an increasingly interdependent gas and electricity system, the federal government should build on the states' efforts in updating the reporting thresholds for natural gas pipeline incidents to better align with the power plant outage standards and create a national standard. We recommend that pipeline incidents of sufficient size to trigger a mandatory power plant outage report should be reported. This additional threshold should be a specific requirement of pipeline systems with active firm supply contracts with power plants. This recommendation is based on the agreement between the pipeline and the power plant that a firm contract is meant to imply: there will be no unplanned curtailment of natural gas service unless necessary in an emergency.

Construction of any new standards should be based on the average amount of natural gas heat input required to produce a unit of electricity (the power plant heat rate) and modified to correspond to the most stringent power plant outage standards. The new standard should also be periodically revisited

Box 2. PARTIAL GAS FAILURES ARE ALSO A PROBLEM

Complete natural gas outages are not as common as failures that drop the pressure in the pipeline. Power plant facilities are designed to receive natural gas from pipelines at a contracted pressure and volumetric flow rate based on pipeline capacity and their generator equipment specifications. For example, two common natural gas turbines built by General Electric (GE), the 50-megawatt model LM6000 and the 85-megawatt 7EA, require incoming natural gas pressures of 290 and 675 pounds per square inch (psi), respectively. The Natural Gas Supply Administration reports that natural gas is typically transported in interstate pipelines at pressures between 200 psi and 1,500 psi. The lowest-pressure interstate pipelines require power plant operators to maintain additional on-site compression equipment to run either model of the GE turbines. Pressure reductions in the lowest-pressure interstate pipelines add stress to these on-site compressors. Even for the highest-pressure pipelines, a 55% drop in pressure would put a generating unit using the 7EA at risk of operational failure. An event causing an 80% reduction would put the LM6000 at risk of operational failure..

or updated to account for technological advances.

For pipelines with firm gas service contracts to serve power plants of over 20 MW nameplate capacity, events that reduce the pipeline's ability to deliver to a plant gas equivalent to 25,000 standard cubic feet per hour should be reported. Pipelines with firm service contracts in place to serve power plants with nameplate capacity of 20 MW or less should report events that reduce the pipeline's ability to serve the plant by 900 standard cubic feet per hour. These thresholds are based on the average heat rates of an advanced combined-cycle power plant and a baseload distributed generation plant, respectively. They are scaled to represent 2% of the median plant's net maximum capacity, the power plant reporting threshold.

During the development and implementation of this new standard, stakeholders of the electric and natural gas industries should be consulted. We recommend that representatives from the American Gas Association, the Gas Technology Institute, NAPSR, PHMSA, and NERC should be included. During meetings with these groups, a key topic of discussion should be to better define what "an event that is significant in the judgment of the [gas system] operator" should include for natural gas pipeline incident reporting and to whom certain types of significant events should be reported. Pipeline operators closely guard their data for internal use. The new standard should be crafted in a manner that preserves proprietary trade secrets while also identifying the information that must be collected to conduct reliability analysis of the whole pipeline network.

We also recommend that the government use the New Mexico and Aliso Canyon events as the impetus to follow the electricity sector's example by designating a central entity to oversee the reliability of the natural gas delivery system. After the 2003 Northeast electric blackout, Congress passed the Electric Policy Act of 2005. The act authorized FERC to appoint an Electric Reliability Organization with authority to establish and enforce mandatory reliability and reporting standards for electricity utilities throughout the United States. In 2006, FERC appointed NERC to that role. Similarly, Congress and FERC could require the establishment of a national natural gas pipeline reliability organization.

The PHMSA data discussed earlier comes from an organization with the mission of "protect[ing] people and the environment by advancing the safe transportation of energy and other hazardous materials that are essential to our daily lives." Because safety is PHMSA's core mission, their data are unsuitable for conducting a thorough reliability analysis of the natural gas network. Instead, the effort to organize a central, NERC-like gas reliability organization could be spearheaded by a group such as NAPSR, with ties in both industry and government. Congress should replicate what it did for electric power.

Experts at NERC should provide guidance to the gas reliability organization. NERC's involvement in the early stages of this effort could provide not only important lessons learned during its own establishment but also the foundation for a collaborative relationship between NERC and its gas counterpart. Given that the United States produces the largest share of its electricity from natural gas, it is critical to coordinate reliability issues between the two grids.

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Recommended reading

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