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CIGRE US National Committee
2017 Grid of the Future Symposium

Transmission System Reliability with Changing Generation Mixes

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SUMMARY

The rapid introduction of renewable technologies and increased reliance on natural gas as the fuel source for generating electricity provide significant opportunities and risks to the North American electric power systems and electric power markets. Extreme care must be taken so that the adoption of renewable technologies and the shift in fuel sources do not undermine the reliability and resilience of the electric grid.

The power industry is at a crossroads: how will the industry reliably generate its electricity given the various environmental policies and economic considerations (in particular, natural gas being deemed prevalently more economical than nuclear and coal)? As a consequence, care must be taken to make sure the reliability of the electric power system (i.e., the ability of the electric power system or its components to adapt to changing conditions and withstand and rapidly recover from disruptions, whether natural or manmade) is not negatively affected by this change. Recognizing this crossroads, several organized markets and balance areas of the electric power system have assessed the impact of high penetration of natural gas generation on system reliability. Those studies concluded that the natural gas resources would be adequate for current and future anticipated electric systems if a robust gas pipeline infrastructure exists to serve electricity generation. However, it has only been recently that PJM has highlighted notable differences between the available infrastructure and the contractual availability and allocation of the natural gas infrastructure to meet the needs of the power generation sector.

This paper examines various definitions of fuel diversity and security within an electric power system through evaluating various economic, reliability, and environmental dimensions of fuel mix and exploring the impacts of various scenarios on fuel dependent energy systems. It identifies options to address fuel diversity and security, so the industry can maintain the high degree of reliability and resiliency in a balanced and economically efficient manner, both in the short and long term.

KEYWORDS

Reliability, Resilience, Resource Mix, Fuel Diversity, and Electric Power Markets.

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INTRODUCTION

Most of the new power plant capacity added in the United States in the past two decades relies on natural gas to generate electricity. Natural gas prices have tended to fluctuate over the years, including rather dramatic fluctuations during the winters of 2013/2014 and 2014/2015. Such dramatic short-term fluctuations often have a disproportionate effect on wholesale electricity prices in certain power markets in the U.S., such as the MISO, PJM, New York, and New England markets.

The changing resource mix in these electric power markets is largely influenced by:

- Environmental regulations
- Recent and forecasted preponderance of low-cost natural gas,
- Increasing penetration of renewable resources, including behind-the-meter distributed generation
- Demand response
- Retirement of coal and nuclear power resources.

Considering the retirement of coal- and nuclear generation, stakeholders have questioned whether the system is losing too many resources that historically have provided the power system stabilizing inertia, voltage support, and ramping and regulation under various emergency conditions to maintain transmission system security. From a resource adequacy perspective, it is necessary to address whether the system is becoming too dependent on natural gas and renewable resources, which could adversely impact the ability of the system to provide generation supply to meet the demand all the time.

A common belief among advocates of greater fuel mix diversity is the continuing expectation that by diversifying a power system's fuel and technology mix, the system will be able to withstand fuel supply or delivery disruptions, fuel supply vulnerability and price volatility, and technical and manmade disturbances on the system. Advocates draw analogies to the well understood attributes of a diversified stock portfolio with balance of quality and risk profile, or the common sense appeal of "not having all of your eggs in one basket". But apart from these rationales, there is little consensus on what a balanced "fuel diversity" would look like due to the fact that there is no reliability standard guiding the performance and design of the fuel delivery systems.

INDUSTRY PERSPECTIVES ON FUEL DIVERSITY AND MARKET IMPACT

On March 30, 2017, PJM published a comprehensive whitepaper on fuel diversity and security entitled, "PJM's Evolving Resource Mix and System Reliability" [1]. In the whitepaper, PJM has thoughtfully defined fuel diversity in terms of the impacts on a generator's ability to provide reliable services to electric grid operations.

Regulatory bodies such as the National Association of Regulatory Utility Commissioners (NARUC) have also weighed in on the meaning of fuel diversity. A typical example of what "fuel diversity" means to NARUC can be found in its 2004 resolution encouraging "state commissions and other policy makers to support the concept of fuel diversity for electric generation." Concerned about the increasing dependence of the nation's generation mix on natural gas at a time of rising prices, NARUC's 2004 Resolution on Fuel Diversity called for a "reliable and balanced long-term fuel mix" for power production [2]. In a prior resolution on national electricity policy, NARUC supported actions and policies to "assure adequate, reasonably priced, reliable, safe, and environmentally sound electricity." To achieve this goal, NARUC called for federal legislation to encourage (among other things) "diverse, plentiful and environmentally responsible energy supplies," with "additional fuel- and technology-diverse supply resources to meet the nation's growing energy demands."

The Federal Energy Regulatory Commission (FERC), in a 2014 technical conference [3] following the 2014 polar vortex, also demonstrated the urgency to address the concerns of whether the evolving resource mix is resulting in a loss of diversity that will lead to future reliability and resiliency problems.

The Institute of Electrical and Electronics Engineers (IEEE) also provided its comments and insight on the fuel diversity issue in its input to the Department of Energy's Quadrennial Energy Review in September 2014 [4]. With continuing retirement of coal and nuclear power plants, and with the level of renewable energy and demand-side actions increasing, "additional gas pipeline capacity, accompanied by supply contracts, is required to meet the growing demand for natural gas for power generation". The industry "must look across its entire asset portfolio, sometimes involving different organizational silos, to determine what optimal mix of investments will produce the greatest gains in reliability and resiliency."

An organized market may have a well-balanced system wide resource mix. However, the system-wide picture does not necessarily mean the different sub-systems maintain the same level of resource balance; therefore, a strong transmission grid among the sub-systems is required to bridge the gaps.

Take PJM as an example, while most of the population (and electric load) is located along the Eastern Seaboard and in northern Illinois, much of the low-cost electricity supplies (hydroelectric, nuclear, and coal) are located outside of these regions. Often, PJM cannot fully dispatch all low-cost power production facilities to meet the load due to electrical transmission congestion. As a result, the relatively nearby gas-fired plants, and gas- or oil-fired peaking plants under stress conditions, must operate locally to keep the lights on. When a natural gas pipeline is congested or interrupted, the natural gas-fired generation capacity may not be available for electricity generation, which is a key factor to measure the ability of the electric system to operate reliably and have the resilience to recover from an emergency. In particular, the current infrastructure of gas pipelines represent a single point of failure for many generators, and from an engineering design perspective, redundancy should be addressed in the similar way as the N-1-1 criterion in the electric system planning as the portfolio mix evolves toward more gas resources.

In the U.S., the build-out of natural gas pipelines has been purely based on firm contracts for pipeline capacity needs. These firm contracts are primarily with gas utilities to provide gas for winter heating purposes and other industrial and commercial customers; very little of the capacity is for generating electricity. While the firm gas contract itself has governing performance and availability requirements, there is not a reliability standard for the natural gas industry. Not knowing how reliable a natural gas pipeline is, or not requiring contractual obligation for the gas supply, makes gas fired generation vulnerable to gas unavailability.

It has been easier to site relatively large and diverse power plants (including coal and natural gas projects) in the central part of the PJM system. Some states in this area have significant indigenous resources for coal-fired generation in western Pennsylvania, West Virginia, and Ohio, as well as natural gas-fired generation due to their proximity to the Marcellus and Utica shale gas formations. Without a robust and congestion-free electric transmission system, the generation capacity in the well-balanced central PJM region cannot be delivered to the load centers to provide economic and reliability services to the consumers. Similarly, without firm natural gas contracts, the gas-fired generators next to the load may have to compete with the load for natural gas, rendering less reliable or unavailable generation to serve the load when natural gas pipelines are congested by firm-contracted non-generation use.

There are over 300,000 miles of interstate and intrastate natural gas pipelines crisscrossing the United States. With abundant natural gas supply and close vicinity to the pipeline, many natural gas fired power plants are connected to one of these pipelines. A failure of the pipeline can result in multiple power plants being unable to produce electricity to supply the load or to maintain transmission system security. This single common mode failure can affect more than one transmission control area, causing simultaneous resource shortfalls in multiple regions and curtailing reliability assistances between the regions.

The current resource mix is the result of countless decisions made by public and private decision makers. Considerations have included a complex array of public policies, economic and technological conditions, capital market conditions, electrical infrastructure layout, consumer preferences, and siting politics highlighted by "not in my backyard" or NIMBY. As a consequence, the electric transmission system in the United States consists of increased natural gas generated electricity, delivery, and use that present reliability risks and unanticipated consequences with the changing resource locations and mixes.

For system planning, it is imperative to effectively mitigate the risks brought on by a concentration of a single fuel to the system reliability. It is also prudent to assess the potential of the unintended consequences now, while the current electric system still has an adequate level of resource mix to mitigate the risks.

IMPACT OF RELIABLE FUEL SUPPLY ON TRANSMISSION SECURITY

Transmission security is the ability of the power system to withstand disturbances, such as short circuits or unanticipated loss of system elements, and still continue to supply and deliver electricity. Security is assessed deterministically, with potential disturbances being applied without concern for the likelihood of the disturbance in the assessment. These disturbances, in the form of single-element and multiple-element contingencies, are categorized as design criteria contingencies (commonly referred to as N-1 and N-1-1 contingencies) as required by the North America Reliability Corporation (NERC). The impacts when applying these design criteria contingencies with appropriated preventive and corrective generation dispatches are assessed to ensure no thermal loading, voltage, stability, or breaker duty violations will occur.

Needless to say, maintaining transmission security requires the generators to have fuel available and ready to participate in transmission security constrained generation dispatch and re-dispatch all the time. Many NERC regions also require the system operators to assess the power system and determine if it can withstand extreme contingencies without uncontrolled load curtailment. It is anticipated that transmission security without explicit recognition of fuel availability will be a long-term challenge, particularly in light of a natural gas pipeline system planned without a reliability criterion per se.

Including gas pipelines in transmission planning is imperative as multiple generating units connected to a single gas pipeline become more common. A mandatory reliability planning criterion that requires consideration of catastrophic failure events in terms of extreme contingencies could help the transmission planners and operators systematically analyze, capture, and plan for catastrophic events. Such extreme contingencies could include a gas pipeline rupture that causes multiple gas fired plants to become unavailable or a common mode gas infrastructure failure rendering several pipelines out of service, particularly during a sustained cold snap or an earthquake. These types of infrastructure failures would render even gas delivered on a firm contractual basis unavailable.

Interruption of the natural gas supply could also stem from the aging pipeline system in this country. Per the 2015 DOE Quadrennial Energy Review [6], over 50 percent of the gas transmission and gathering pipelines were constructed in the 1950s and 1960s. As the system ages, equipment operating costs increase and reliability decreases. With limited capital available for wholesale replacements, it is necessary to develop sound strategies to control the symptoms of aging within the resource mix and fuel security framework to maintain reliable and economic services to the consumers in the region.

Resources could be unavailable because, collectively, they rely either on a single technology or a single fuel. To be resilient, the power industry must take into account the possibility of larger scale disruptions of the natural gas supply system, similar to the reliability standards adopted in electric system planning and operations and in the cyber security (e.g., CIP-014-like) development.

The importance of strengthening the natural gas infrastructure requires focusing on the critical dependence between the regional power grid and gas pipelines. Expansion to either system, whichever is more economic to the consumers, is an increasingly crucial issue for regulators, industry stakeholders, and consumers. It is technically true that diversified generation mix with robust gas and electric transmission provides a unique value to power system reliability.

ADEQUATE FUEL SUPPLY – AN INTEGRAL PART OF RESOURCE ADEQUACY

Vulnerabilities in gas supply limits electric generation

While the gas supply may be sufficient, significant vulnerabilities exist: shortfall of pipeline capacity supplying the load centers along the coasts, shortfall of pipeline capacity to access storage and production, and disruptions in supply or storage especially during winter peak season. There is an increased risk to natural gas delivery under extremely cold and high-load conditions. As extreme weather events such as a polar vortex, a supposedly once-every-60-year event, happened twice in the past four years, such events can cost consumers millions of dollars, which specifically highlights the importance of resilience in the natural gas supply system to electric generation.

The electric system operations during the January 6 through 8, 2014 "Cold Snap" is briefly recapped as follows:

- January 6 evening, PJM reported the loss of 3,000 MW of Western Pennsylvania and Ohio generation, and load conditions were 5,000 MW over forecast; at 21:00, PJM declared a NERC Energy Emergency Level 1 & 2.
- January 7, regional electric conditions were "tight." PJM reported additional generator derating and predicted possible need for voltage reduction over the peak; IESO predicted higher loads and export curtailments; NYISO was tight. Added to the dire situation were interruptions in regional pipeline conditions: the Texas Eastern pipeline company lost their Delmont Compressor Station in Western PA early Tuesday morning, creating gas curtailments that impacted some generation capability for PJM, NYISO, and ISONE.

All conventional forms of generation, including natural gas, coal, and nuclear plants, were challenged by the extreme conditions. Generators are required to submit outage data after the outage has occurred. Figure 1 shows that the 42 percent of forced outages were due to equipment failures. The other key reason (24 percent of the forced outages) was a lack of gas to start up and/or run generating units.

During this event, there was enough gas supply and storage, but the pipelines were either congested or failed to deliver the natural gas to the generators. A resilient energy system should anticipate, minimize the impact of, and quickly recover from such shocks. It also should provide alternative means of satisfying energy service needs in the event of changed external circumstances.

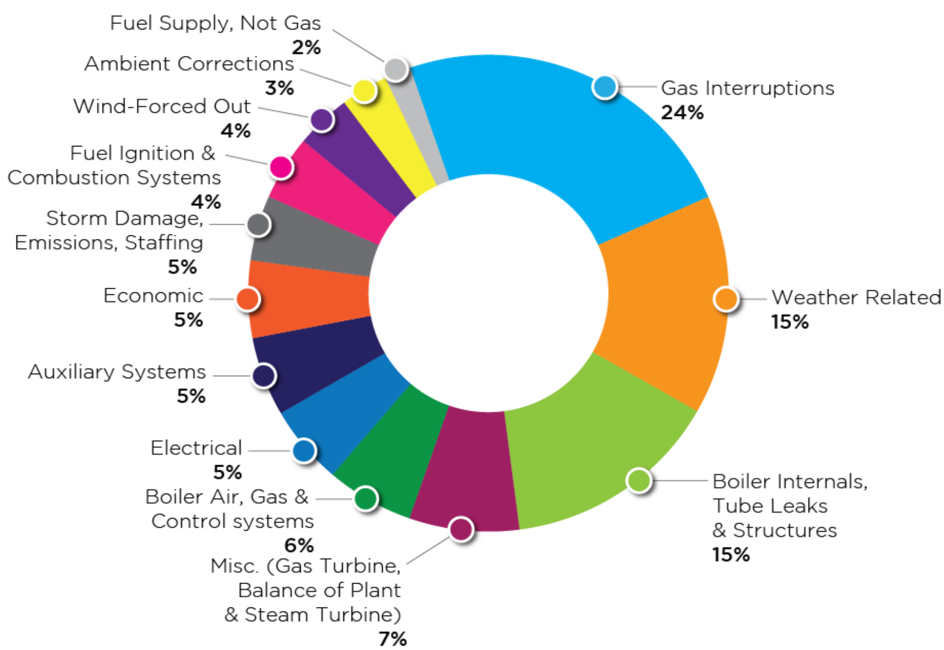

Figure 1 – Causes of Forced Outages in PJM (January 7, 2014) [5]

Firm gas contract issue

Most gas-fired plants served by local distribution companies (LDCs) do not have firm gas contracts. Gas's retail load has higher priority during cold weather, which makes it difficult for gas-fired generation to procure gas; it is especially difficult to procure gas on short notice in order to react to real-time market signals during a gas Operational Flow Order (OFO). In April 2015, PJM revised how capacity resources were defined and compensated in the capacity market in order to address the risks of fuel security associated with individual generating plants. The new capacity product, called Capacity Performance, incentivizes generators to commit to more stringent performance requirements, which includes the "firming" of fuel supply (through firm gas service contracts, firm service contracts with greater flexibility, or the installation of dual-fuel capability). While the Capacity Performance improves individual generator availability, the limitation of an LDC to supply natural gas for generation in competition to gas retail demand obviously still exists. For a reliable fuel supply, PJM, as well as the power industry as a whole, must take into account the possibility of larger-scale disruptions of the natural gas supply system in system planning and resource adequacy assessment.

The rapid and growing switch to natural gas has exhausted available interruptible service during periods of high non-power winter gas demand; however, only short term market mechanisms have been explored in the marketplace. A long-term solution has not adequately been investigated to address the fuel delivery vulnerability issue.

Early on, natural gas generation made good use of the headroom in gas pipeline systems through the contracting of non-firm gas services. However, the scarcity of pipeline headroom has become apparent in recent years, as more gas fired generation has come into operation and other commercial and industry sectors have increased their use of natural gas. , With gas pipeline services unchanged, continued reliance on such non-firm gas services will inevitably reduce the generation availability, and, hence, impact system reliability and resilience.

Remote gas storage issues

Most gas storage is remote from the load centers, while the gas-fired plants are close to the load. When gas pipelines/LDCs get constrained, these remote storage facilities cannot deliver the gas to the gas fired generators. In PJM, both natural gas production and gas storage are concentrated in central PJM, whereas the load centers are far away in eastern and far western PJM. Although the gas supply may be sufficient, the pipeline capacity limits the gas delivery to the gas fired generation. Adding to these congestion issues is the aging gas pipeline infrastructure, which raises further concerns regarding the vulnerability of gas supply for electricity generation.

Aging infrastructure and nuclear closures may lead to the continued reliance on non-firm natural gas contracts for gas-fired generation. With the increasing gas-fired generation close to the load, it could exacerbate the existing dependence on natural gas for power production in these areas.

Fuel availability and different fuel-burning rates limit generation

Some gas-fired units have the capability to use an alternate fuel (dual-fuel capability), which increases flexibility when gas supply becomes tight. The predominant alternate fuel is oil. While dual-fuel units increase flexibility, there are still challenges in operating the units on oil due to permit-defined environmental restrictions, resupply challenges, and increased failure rates for unit start-up.

Gas-fired generation typically has little-to-no on-site dual-fuel storage, as compared to coal and nuclear generation which are less prone to fuel transportation issues during a cold snap (they also tend to have a sufficient on-site fuel supply for contingencies). Additionally, extended, cold-weather-related oil-burning rates for gas fired generators can limit generation production because environmental restrictions can limit peaking units' total generation hours in a year, alternative fuels tend to impose lower replacement burning rates, and burning alternative fuels can be restricted by

NOx emission limitations. This is further complicated by the fact that environmental restrictions tend to be even stricter the closer the generation is to the load centers.

Therefore, to mitigate natural gas vulnerability, not only should the dual-fuel option be considered, but also other options such as firm gas contracts and electric transmission to allow clean and reliable capacity resources to reach the load pockets. A balanced approach to mitigating the gas vulnerability should include reliability, resiliency, and economic comparisons among various alternatives such as gas infrastructure expansion, firming up gas contracts, dual fuel, clean coal and nuclear, and electric transmission expansion.

COMMON MODE FAILURE WITH EXTENDED REGIONAL RELIABILITY IMPACT

The increased production of Marcellus and Utica shale gas has increased the natural gas supply to the PJM region, as well as to PJM's neighboring regions – the Midwest, New York, Eastern Canada, and New England – via the interstate natural gas pipelines that crisscross the central PJM area. As with the natural gas system, the regional wholesale markets (MISO, PJM, NYISO, IESO, and ISONE) provide electricity trading and resource capacity sharing, both in real-time and on a long-term basis. Should infrastructure disturbances occur to the natural gas pipeline, not only would they interrupt generation in one region, but also in other regions, causing simultaneous resource shortfalls in multiple regions and curtailing reliability assistances between the regions.

With its 300,000 miles of interstate and intrastate gas transmission pipelines, the United States has experienced disruptions. According to the Energy Information Administration (EIA), as a result of the September 2008 Hurricanes Gustav and Ike, "almost all of the natural gas production and processing capacity in the [Gulf coast] area was shut in, with continued shut-ins affecting production into December 2008." Fifty-five major natural gas processing plants were in the path of the hurricanes, representing 38% of U.S. processing capacity. Twenty-eight pipelines, most of which move natural gas onshore to processing plants, declared force majeure (occurrences beyond their control) in September 2008, and many were shut down.

Adequate and reliable primary fuel is critical to maintaining transmission security and system reliability and resilience. Overreliance on a high concentration of a single fuel type could make the transmission system vulnerable to fuel supply interruption. Gas interruption is a multi-regional issue. When gas is not available for generation, it could affect the resource adequacy of multiple regions. For example, when a gas pipeline company sends out a gas alert and an OFO, all of the generation downstream is affected. Therefore, the impact of natural gas supply interruption in a much larger footprint should be always planned for and analyzed in terms of resource adequacy, interregional system coordination, and system security and reliability.

EXAMPLE: FUEL DIVERSITY AND RESOURCE MIX IN PJM

The PJM's system-wide resource mix has become increasingly balanced over time. In 2005, coal and nuclear resources generated 91% of the electricity on the PJM system. Policy initiatives, technology improvements, and economics spurred a shift from coal to natural gas and renewable generation. From 2010 to 2016, PJM's coal-fired units made up 79% of the MWs retired, and natural gas and renewables made up 87% of new megawatts placed in service. PJM's installed capacity in 2016 consisted of 34% coal, 35% natural gas, 19% nuclear, 7% renewables (including hydro), and 5% oil as shown in Figure 2.

Like the other organized markets in the U.S., the PJM reliability planning and resource adequacy assessment does not explicitly recognize the value of fuel diversity; for instance, the Capacity Emergency Transfer Objective (CETO) and Capacity Emergency Transfer Limit (CETL) (CETO/CETL) is a fuel-neutral process. Enhancements in traditional capacity procurement or economic dispatch are needed to maintain system reliability by recognizing the fuel supply vulnerability in the resource adequacy assessment and determination.

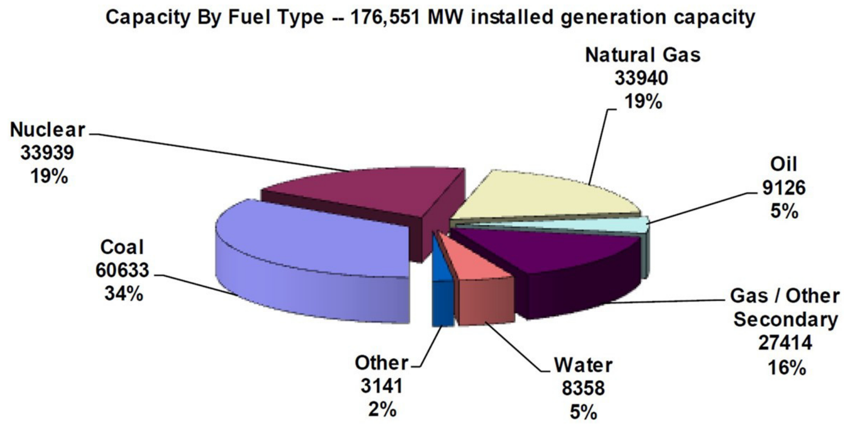

Figure 2 – PJM Capacity by Fuel Type [1]

Generally, the power industry today can have multiple portfolios that meet regional resource adequacy criteria, but they may not have adequate ability to provide operational readiness and flexibility required for reliability. As a consequence, the electricity reliability may not be sufficiently covered.

For example, the PJM whitepaper [1] stated that the less-than-desirable performance of a generation mix portfolio was largely due to the incremental replacement of coal with increasing unforced capacity shares of solar or wind, and a moderate share of natural gas. Unlike coal, these resources either did not exhibit, or only partially exhibited, generator reliability attributes that are stressed during extreme weather conditions such as Ramp Capability and Fuel Assurance. These portfolios were not classified as at-risk-for-underperformance, but they did not provide the same level of generator reliability attributes as the today's as-found system. A trend toward portfolios that fall within this category would indicate that PJM and its stakeholders should consider new technology requirements and market rules to address potential operational reliability and resiliency shortfalls.

It is important to note that most of the desirable portfolios in the PJM whitepaper [1] were composed of relatively large unforced capacity shares of coal, nuclear, and natural gas, with moderate unforced capacity shares of wind and solar to provide the full range of generator reliability attributes. Capacity performance is, therefore, designed to address the risks of fuel security associated with individual generating plants by incentivizing the "firming" of fuel supply through firm gas service contracts, firm service contracts with greater flexibility, or the installation of dual fuel capability, which combines back-up fuel oil with primary natural gas fuel. The flexibility of dual fuel units has to be balanced with the ability of extended production duration and emissions restrictions. Or put it differently, the voluntary action incentivized by the market rules may not fundamentally address the natural gas vulnerability, as potential transmission security violations can occur when physical or permitting limitations prevent the generator from generating.

Up to this point, many organized markets have enabled the wholesale markets to accommodate continued natural gas and renewable generation integration. When one type of fuel is unavailable, other types of resources can come in to provide the reliability services. Going forward, the fuel diversity and security discussion should be structured to be compatible with the changing need of the electric system operations in the competitive marketplace through continued market enhancement to ensure a reliable fuel diversity and adequate resource.

RECOMMENDATIONS AND CONCLUSIONS

The rapid introduction of renewable technologies and increased reliance on natural gas as the fuel source for generating electricity provides significant opportunities and risks to the electric power system and market. Extreme care must be taken that the adoption of new technologies and the shift in fuel sources do not undermine the reliability and resilience of the electric grid.

The electric power industry in the United States, with the solid engineering practice of meeting load requirements with diversified resources in the past, has been providing reliable services to the consumers with adequate generation and transmission resources. Today, as new types of resources begin dominating the resource mix and baseload generation is retiring, the system is facing a daunting task to ensure adequate resources under all conditions. Without consideration of contingency plans and key operating characteristics of the various resources, as well as risk of fuel supply, a simple replacement of existing resources with intermittent resources balanced with natural gas generation would be imprudent. Similarly, the nation's electric system is challenged with its ability to continue providing the reliable and resilient electricity services the consumers have come to expect for decades.

It is critical to continue to explore a number of possible short- and long-term policy options that could change the signals in the marketplace. Some options include:

- Maintaining the current level of resource mix – coal, nuclear, gas, hydro, and renewable generation sources – while the electric utility industry, together with the regulators, investigate the long-term consequences of shifting resources to generate electricity and mitigation technologies.
- Enhancing the ability to plan and operate power plants with recognition of the reliability fuel supplies.
- Introducing regulatory policies, reliability standards, and market rules to encourage investments in fuel delivery, energy storage, and storage replenishment, as well as transmission infrastructure, to allow for a more diverse system of gas and electric transmission.
- Putting in place emergency measures to mitigate the effects of certain types of adverse events on the system.

Each of these approaches involves trade-offs, and policy makers and other stakeholders need to be aware of these issues as they consider if and how to address fuel diversity and security issues in the future.

Maintaining and improving fuel diversity and security will lead to less volatile electric prices, improved reliability, and positive environmental impacts, all as part of a resilient system. It is essential that public policy makers, utilities, consumers, and energy suppliers confront the risks associated with inadequate fuel diversity and fuel delivery. Market forces should be harnessed, and reliability planning principles should be utilized to encourage signals that will lead to support for the protocols and technologies necessary to move the industry towards an optimum fuel diversity profile.

Grid resilience is increasingly important considering the number of associated risks – cybersecurity, more extreme weather events, increasing dependence of reliable electric services on natural gas pipelines, aging infrastructure, and resource category retirements. A well thought through process for the long-term infrastructure solution with good engineering practices will benefit the consumers in the long run.

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