Reliability Assessment of Diesel vs. Natural Gas for Standby Generation

INDUSTRY NEED

In the past, gaseous fuels were avoided in emergency power or standby power supply (EPSS) applications greater than 150kW based upon cost effectiveness, power density, and perceptions of durability and fuel reliability. Recently, cost-effective natural gas engines that are environmentally friendly and can sustain long run times have been developed and are now common in the market. These advancements in the design and controls of natural gas generators for EPSS offer several advantages for the end user. However, diesel gen-sets are currently the established technology due to regulations requiring on-site fuel storage and perceptions regarding the reliability of utility gas distribution.

EPSS generators are installed nationwide by a wide variety of residential, commercial, and industrial customers to avoid power disruptions. There are in excess of 250 gigawatts of standby generator power in the U.S. with over 15 gigawatts of new capacity added each year. Even more market potential exists as voluntary versus code-driven standby power increases. Today, in markets where volume is driven by code requirements, the natural gas share is 20% to 30%. Interestingly, for systems less than 150kW, more typical of voluntary non-code-driven installations, the natural gas share is close to 70%.

In tens of thousands of code-driven EPSS installations each year, local authorities having jurisdiction (AHJ's) are the determining factor in the selections of the systems and fuels that can be used. How those AHJs perceive and regulate fuel choices is a primary reason for the low percentage of installed natural gas EPSS generators.

The National Electric Code (NFPA 70/NEC) and National Fire Protection Association NFPA 110 are the most frequently referenced standards for specifying EPSS generators. NFPA70 NEC 700.12(B)(2) states, "*Where internal combustion engines are used as the prime mover, an on-site fuel supply shall be provided with an on premise fuel supply sufficient for not less than 2 hours' full-demand operation of the system*". However, article 700.12(B)(3) states an exception, "*Where acceptable to the authority having jurisdiction, the use of other than on-site fuels shall be permitted, where there is a low probability of a simultaneous failure of both the off-site fuel delivery system and power from the outside electrical utility company*".

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Reliability Whitepaper

"*Reliability of fuel supply tends to be of great concern for authorities having jurisdiction (AHJs). On-site fuel (most often diesel) is typically required for life-safety applications, and many mission-critical applications like 911 call centers specify it because it is perceived to be more reliable. Nonetheless, maintenance issues and delivery concerns of diesel fuel in an emergency, combined with the reliability and cost-effectiveness of natural gas, must be considered in a standby power system. NFPA and NEC offer provisions for the use of natural gas in standby power applications that had previously been the clear domain of diesel-fueled systems. There are also many ways to work with the AHJ to clear the way for the use of gaseous fuel in a standby power system.*"

https://www.generac.com/GeneracCorporate/media/Library/pdfs/whitepapers/0200930SBY-nat-gas-whitepaper.pdf

Overall, NFPA regulations state off-site natural gas supply *is allowed* for EPSS generators but only if proven reliable. Unfortunately, there are a lack of historical supporting data on simultaneous geographical electrical and gas outages.

Advanced natural gas EPSS generators can also be used in demand response applications. In such applications, utilities stand to benefit by reducing peak demand to prevent regional deficiencies in capacity. During times of peak demand, natural gas EPSS generators can provide on-site power independent of the grid, or operate in parallel with the grid. In some cases, the electric utility may even be able to reduce or defer infrastructure build out, and improve grid asset utilization by lowering peak demand.

DIESEL STANDBY POWER ISSUES

Traditional perception within the market is that diesel engines are the most reliable prime movers for all EPSS applications. However, despite their consequentially widespread use, diesel generators are not without their own very real reliability concerns. Outages associated with major weather events have highlighted diesel-fueled generator vulnerability, including improper or inadequate fuel maintenance practices, and the difficulty or impossibility of fuel replenishment in the midst of prolonged and wide-scale outage events.

Common diesel-fueled generator concerns include:

- Limited tank capacity,
- Fuel degradation,
- Tank condensation and corrosion,
- Microbial contamination in fuel,
- Hydrocarbon release, and
- Tank access.

Preventative routine maintenance is critical for ensuring that a diesel-powered standby generator will start and run when needed. If the diesel generator is subject to extreme conditions, such as continuous operating duty, high ambient temperatures, outdoor exposure, salt/salt water exposure, or sand/dust exposure, then the frequency of preventative maintenance must be increased to ensure proper diesel generator operation when needed.[1]

On-site storage of diesel fuel is subject to contamination and deterioration over time, presenting a significant maintenance issue for diesel generators. According to Exxon Mobil, diesel fuel can be stored for up to one year without a reduction in quality if it is kept clean, cool, and dry. Longer storage periods require filtrations, fuel stabilizers, and biocides to prevent water and biomass contamination. [2]

Water vapor accumulates and condenses in the fuel tank and must be periodically drained from the tank along with any sediment present. Wet stacking, which is the buildup of unburned diesel fuel in the engine and exhaust, has been estimated to cause up to 65% of diesel generator maintenance problems. This is often caused by loading the generator below 50% rated load. [3]

Regular generator set “exercise” is required to maintain fuel quality. The NFPA regulations for EPSS require monthly 30-minute tests (or annual 1.5-hour tests) to prevent wet stacking. Storing fuel on-site requires continual maintenance to reduce risks, but also requires new fuel to be purchased periodically. In addition to higher generator maintenance costs, fuel maintenance costs for diesel generators represent a volatile and added operating cost as compared to natural gas generators. Although preventative maintenance can reduce concerns for diesel generator reliability, the work is often not performed and/or overlooked due to time and cost. As a result, diesel-fueled generators often do not perform as expected in required scenarios.

Mechanical failures for pumping diesel fuel from storage tanks to generators can also cause issues. Such was the cause during a power outage at two San Diego area hospitals on September 9, 2011. The fuel pump on the facility’s lone diesel generator failed at Scripps Mercy Hospital in Chula Vista leading to approximately three hours without power. At Sharp Memorial Hospital in Serra Mesa, the full-load diesel generator simply did not come on.[4]

Other instances of hospital diesel generators failing to operate during power outages have been reported throughout the nation, especially during major natural disasters. For example, failure of the diesel generator at a hospital in Connecticut during Hurricane Irene led to a complete patient evacuation. Additionally, during Hurricane Sandy in October 2012, all patients had to be evacuated from both New York University Langone Medical Center and New Jersey Palisades Medical Center when backup diesel generator systems failed to operate. [5]

After Hurricane Sandy, entities that relied on diesel fuel to produce backup power found that one of "*the biggest problems with the liquid petroleum (i.e., gasoline and diesel fuel) supply after Hurricane Sandy was flooding damage to major terminals and docks in the Arthur Kill area of New Jersey. As shortages accumulated, consumers struggled to find gas stations that were functional*."[6]

NATURAL GAS STANDBY POWER RELIABILITY

Natural gas is delivered by underground pipelines connected to the utility main supplies. They are less likely than diesel fuel delivery systems to be compromised during major disasters (except for possibly earthquakes) when the need for passable roadways and available fuel in tanker trucks are required for diesel delivery.

"*The reliability of natural gas supply has been well documented with very few historical outages to firm delivery contracts. Compared to the typical three day (72 hours) fuel supply provided by on-site diesel storage, natural gas sites are expected to operate weeks or months, depending on the available gas storage for a given time of year and the dependence of the regional gas infrastructure on electric power.*"[7]

In addition, the large network of natural gas pipelines coupled with the diversity of gas supply and storage options provide added resiliency in the event of a limited failure to re-route the gas supply from alternate production sources or through alternate transmission pipelines.

Due to the increasing use of natural gas-fired power generation, reliability of the natural gas supply has been the focus of several recent studies by the electric power industry and other stakeholders (e.g., Federal Energy Regulatory Commission, U.S. Department of Defense, and New York State). Natural gas-fired generation rose from 17% to 33% of U.S. power generation over the past decade.[8] It is now the largest fuel source for generation capacity. "*While extremely rare, disruptions in natural gas supply or transportation to power generators have led the electric industry to pursue a better understanding of the reliability implications associated with increasing gas-fired generation.*"[9] Recent studies generally agree that the natural gas utility supply is currently reliable even during prolonged and wide-scale power outages.

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NG/Diesel Whitepaper

"*Traditionally, the choice between diesel-fueled and gaseous-fueled generators has been relatively straightforward. Power density as well as capital cost advantages in large-kilowatt applications typically favored diesel for standby power of 150 kilowatts of electricity (kWE) or more—large commercial and industrial standby applications. However, technological innovations are making gaseous-fueled generators more powerful and more cost effective. Additionally, issues of fuel storage and reliability in diesel-fueled generators are becoming a bigger challenge. Finally, as more and more companies seek to reduce their carbon footprints, they are more open to options that are more environmentally friendly. As a result, standby generator system designers, electrical contractors and electrical engineers have significantly more gaseous-fueled choices than they had before.*"

https://www.generac.com/GeneracCorporate/media/Library/pdfs/whitepapers/0187520SBY-gas-v-diesel-whitepaper.pdf

Historically, there have been very few outages in the natural gas distribution system and firm delivery contracts have been fulfilled with greater than 99.999% reliability.[10] Moreover, the interconnected nature of the natural gas system allows for workarounds due to any problems with transmission lines, with back-up natural gas supply coming from storage or from other producing regions and pipelines. As described by a recent MIT study on energy resiliency for the Department of Defense, the reliability of the natural gas supply is supported by the resiliency of the natural gas transmission and distribution network during a prolonged and wide-scale power outage:

"*The natural gas network has few single points of failure that can lead to a system-wide propagating failure. There are a large number of wells, storage is relatively widespread, the transmission system can continue to operate at high pressure even with the failure of half of the compressors, and the distribution network can run unattended and without power. This is in contrast to the electricity grid, which has, by comparison, few generating points, requires oversight to balance load and demand on a tight timescale, and has a transmission and distribution network that is vulnerable to single point, cascading failures.*"[11]

Furthermore, MIT's study recommends the increased use of natural gas or bi-fuel backup power for military bases to increase energy security for weeks to months rather than the typical three-day supply of diesel fuel.

A recent study by North American Electric Reliability Corporation also highlights the important role shale gas plays in improving resiliency and reducing outages: "*Risks to gas supply shortages can largely be mitigated or reduced with the abundance and geographic diversification of shale plays across North America. Vulnerabilities in gas supply due to weather events can be mitigated or reduced by increasing production in unaffected areas*."[12] Likewise Black & Veatch noted, "*The growth of onshore unconventional natural gas resources in Texas may be expected to help make natural gas supply even more readily available for ERCOT generators.*"[13] ERCOT is the Electric Reliability Council of Texas, which manages the flow of electric power to millions of Texas customers.

A 2013 study by ICF International highlights the advantages of combined heat and power (CHP); however, many of these benefits also are provided by natural gas EPSS generators with appropriate controls to automatically start and run the systems monthly or weekly.

Two of the following CHP benefits highlighted in the study can also pertain to smartly designed natural gas EPSS generation: [14]

- "*Backup generators typically rely on reciprocating engines burning diesel fuel, a polluting method of generating electricity. CHP systems typically burn natural gas, a cleaner fuel, and achieve significantly greater efficiencies, lower fuel costs, and lower emissions*."
- "*Many CHP systems have a permanent source of fuel on demand; for example, most natural gas infrastructure is underground and rarely impacted by severe weather events*."[15]

CANADIAN CODE MODIFICATIONS

In 2007, the Canadian Standards Association's (CSA) approved "*off-site fuel sources*" for emergency generators, CSA C282 (*Emergency Electrical Power Supply for Buildings*).[16] CSA C282 specifies the requirements for life-safety emergency generators, which power life safety loads, such as exit signs or fire-water booster pumps needed to safely evacuate multi-story buildings in event of a power outage, fire, etc. Prior to 2007, these generators were required to have on-site fuel supplies, and virtually all life-safety emergency generators throughout Canada were diesel-fueled. The natural gas option was incorporated for non-healthcare facilities in 2005, and for hospital care facilities in 2009.

REGIONAL CONSIDERATIONS

While the natural gas distribution system has demonstrated reliability in most regions of U.S. and Canada, there are some concerns for areas with high risk of earthquakes, landslides or mud slides, or major flooding events.

A recent white paper by Bloom Energy presents the key risks for natural gas pipeline safety, as well as the mitigation approaches that are used by the gas industry, federal, state and local agencies. "*Public safety is the number one priority for all natural gas pipeline companies and operators.*"[17] According to the U.S. Department of Transportation, the leading cause of pipeline damage is due to human error, such as excavations near existing pipelines. These can be detected quickly, isolated, and resolved quickly. In contrast, the majority of electric grid disruptions (78%) are due to severe weather-related events which are difficult if not impossible to predict or mitigate. The duration of these outages can range from a few hours to several days. In addition, the number of weather-related outages are increasing.[18]

Interruptions due to Earthquake-related Damage

The Bloom Energy report indicates that recent advances in natural gas pipeline materials, such as high-strength steel or polyethylene plastic, provide flexibility to withstand significant earth movement without sustaining damage. Rare pipeline damage caused by earthquakes occurs because of large scale soil displacement rather than ground shaking.[19] According to the Mercalli Scale, it would take a significant earthquake categorized at level 11 out of 12 to cause pipelines to break; this is equivalent to a 7.5 or higher on the Ritcher Scale.[20] Earthquakes of this magnitude are rare; there have only been two earthquakes in the continental U.S. since 1900 with magnitudes above 7.5. Given its location along the Pacific Ring of Fire, Alaska has a higher occurrence of earthquakes of this magnitude, though only nine have occurred within the state since 1900, averaging less than one per decade.[21]

According to the California Seismic Safety Commission, interruptions in natural gas service due to earthquake damage can be initiated by customers or by the gas utility. Despite public service announcements advising customers to shut off service only if they smell gas, hear gas escaping, see a broken gas line, or observe structural damage to the building, customers continue to disconnect gas service as a precaution. In some cases, natural gas utilities will shut off gas service to structures that have been severely damaged or to isolate portions of the gas distribution system where significant damage has occurred. Table 1 displays the customer outages and restoration times for three recent California earthquakes. The variation in restoration time is a function of the number of outages, the size of the service interruption, the quantity of personnel and equipment mobilized to restore service, and logistical difficulties caused by other earthquake damage such as road closures.[22]

For example, utility personnel restored service following the Whittier earthquake, while personnel from other utilities and private contractors were employed to restore service following the Northridge and Loma Prieta earthquakes. Based on experience from these two earthquakes, the maximum level of service restoration for an earthquake producing 100,000 customer outages or more can vary between 10,000 and 20,000 restorations per day.

Table 1 Service Restoration Times for Three Recent California Earthquakes

Earthquake	Number of Customer Outages*	Restoration Time
Northridge	120,000	12 days
Loma Prieta	156,355	9 days
Whittier	20,600	10 days

*Does not include customers affected by the additional time needed to reconstruct gas distribution facilities or structures

Interruptions due to Major Flooding Events

Flooding in and of itself is unlikely to stop natural gas flow, but the intrusion of water into the distribution system can result in an interruption in service.

As evidenced by Hurricane Sandy, flooding arguably poses the most likely weather-related threat to the natural gas distribution system. Compared to the nearly 2 million customers that lost electric service at some point during the storm, 84,000 customers lost natural gas service.[23] Most of these service outages were the result of the two gas utilities, National Grid and Con Edison, shutting off gas valves in coastal areas to isolate pipes threatened by or experiencing flooding from the remainder of the distribution system. PlaNYC noted, "*…Sandy's impact on the city's natural gas system began with a series of preemptive steps that were taken by Con Edison and National Grid. For example, as Sandy approached, the two utilities isolated some low-lying parts of their networks to ensure that any intrusion of water would be limited, rather than spreading system-wide. Both Con Edison and National Grid also shut down several regulator stations in anticipation of the storm…In some parts of the low-pressure distribution system, the pressure of floodwaters quickly exceeded the pressure inside the gas mains, resulting in water intrusion through cracks, holds and other weak points. Meanwhile, in the high-pressure distribution system, floodwaters entered some customer service lines.*"[24]

Low pressure distribution pipelines are typically cast iron and bare steel and generally considered out-of-date infrastructure due for replacement and upgrade. High pressure lines are more likely to be made of resilient coated steel and polyethylene plastic. Entergy, Inc. has been rebuilding the natural gas distribution system in New Orleans, which was inundated with over 4 million gallons of saltwater during Hurricane Katrina and its aftermath. The damaged low pressure system is being replaced with high pressure, high density polyethylene gas pipe, which can withstand pressure up to 99 pounds and would require more than 215 feet of water on top of it to infiltrate the pipe.[25] In addition to the issue of material strength, the pressure differential between the incoming water and the natural gas flow in the pipe means that the low pressure system is particularly vulnerable to the effects of flooding.

Flooding or power outages may also affect control and monitoring equipment associated with gas distribution. In the case of Con Edison, some of their equipment failed due to the loss of power and telecommunications services. Incorporating natural gas backup generators for critical equipment may reduce this risk and improve resiliency for the natural gas supply.

CONCLUSION

In summary, excluding areas with high risk of earthquake activity or out-of-date infrastructure subject to major flooding events, natural gas standby power generation can provide multiple benefits in appropriate applications:

- Reliable delivery of natural gas
- Elimination of risk due to fuel maintenance and storage
- Ability to deliver extended run time during natural disasters
    - Fuel delivery not impacted by impassable roads or inoperable fuel depots
    - No on-site fuel storage capacity limitations
- Environmental superiority
- Lower costs and maintenance

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