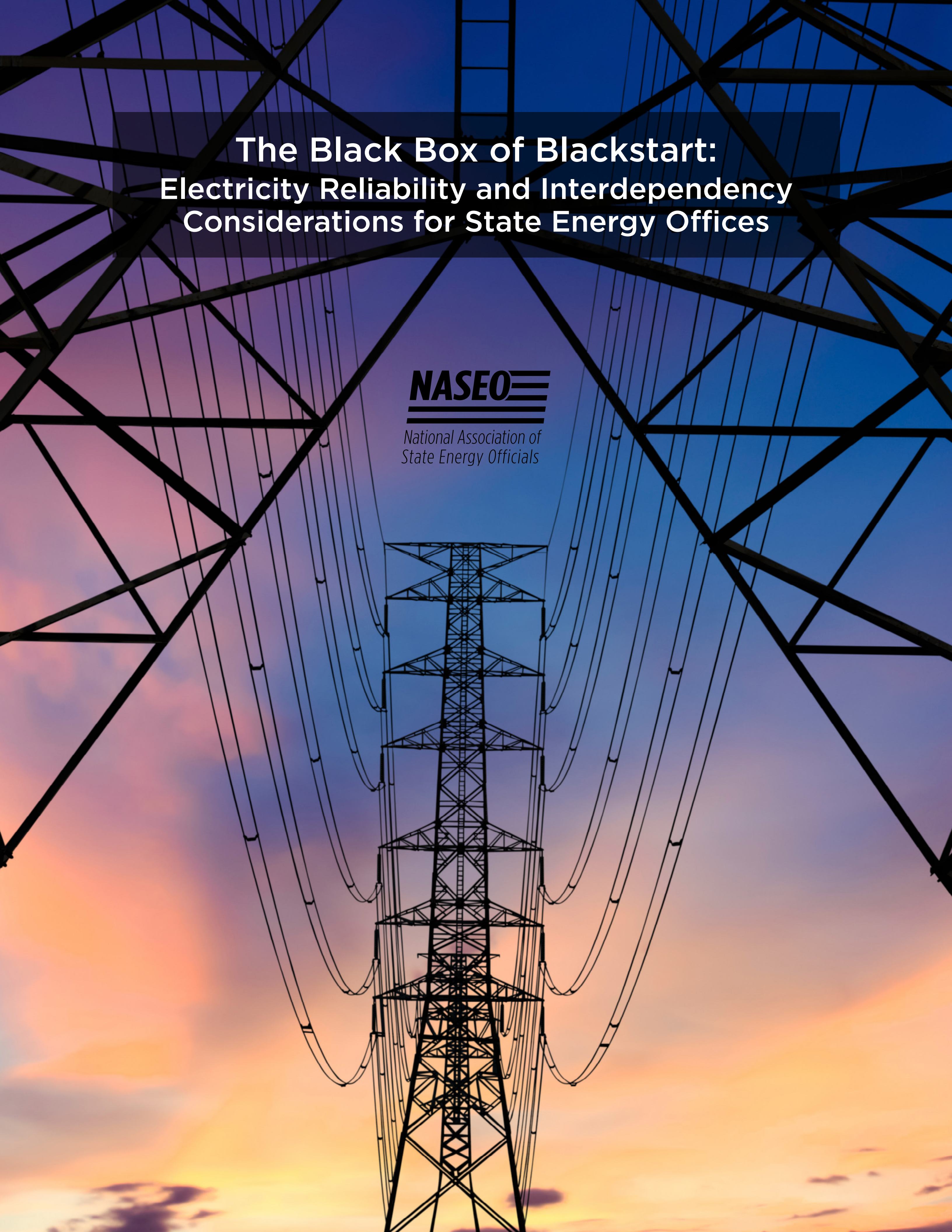
The Black Box of Blackstart:
Electricity Reliability and Interdependency Considerations for State Energy Offices



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Abstract
Most electricity outages in the United States are localized and do not expand outside of state or regional borders or a utility's service territory. However, when large parts of or the entire electricity system are failing (due to an extreme weather event, a cyber-attack or other natural or man-made hazards), blackstart capable generation resources are crucial to restarting the electricity grid. Blackstart resources can be started without electricity from the main grid, thus providing the initial energy needed to repower the larger electricity grid. Without operational blackstart units, restoration time would be significant and impacts of a large outage severe. This briefing paper for State Energy Offices provides background information on blackstart units and the blackstart process. It highlights the importance of blackstart units and outlines how blackstart units are regulated and the changing considerations for blackstart units as the United States' electricity grid undergoes a transformation toward more renewable energy and distributed energy resources (DER). The briefing paper concludes with considerations for State Energy Offices for enhancing blackstart capabilities.

Introduction – The Importance of Blackstart Capabilities

The winter storms impacting Texas and other central region states in February 2021 brought freezing temperatures, snow, and ice, causing significant power outages across the region. Two out of three Texans lost power at some point during the storm and almost half lost access to running water. The impact on the power sector was so severe that the Texas electricity grid came close to suffering a complete blackout. While this larger crisis was averted by curtailing demand and rolling blackouts, the incident highlighted a little known and understood feature required for grid resilience and restoration: blackstart capabilities. When parts of or the entire electricity system are failing (due to an extreme weather event, a cyber-attack or other natural or man-made hazards), blackstart capable generation resources are crucial to restarting the electricity grid.[i] This is due to the fact that blackstart resources can be started without electricity from the main grid, thus providing the initial energy needed to repower the larger electricity grid. While a complete failure of parts or the entire electric grid is extremely rare, the winter storms in Texas, and other events in other states and regions over the decades, highlight the importance of having functioning blackstart capable generators. During the storms 9 of the 13 primary generators designated as blackstart capable generators in Texas were not operating consistently and 6 of the 15 secondary blackstart capable generators were experiencing temporary outages or lack of fuel.[1] If the electricity grid had suffered a complete blackout, blackstart units would not have been available. Following winter storm Uri, the Texas legislature took several significant steps to enhance the resilience of the electricity grid (more on that below).

Most electricity outages in the United States are localized and do not expand outside of state or regional borders or a utility's service territory. Localized outages do not require blackstart units to re-energize the part of the system affected by an outage as it is much easier and more cost-effective when done through a transmission link with a region that still has an adequate power supply. Thus, the need to use a blackstart unit is extremely rare, but when it is required, operatable units are critical in avoiding catastrophe. Blackstart units have been deployed several times in the United States. One example occurred during the Northeast blackout in November 1965 that affected Connecticut, Massachusetts, New Hampshire, New Jersey, Pennsylvania, Rhode Island, Vermont, and parts of Ontario in Canada. The outage left over 30 million people without electricity for up to 13 hours. A survey by the Federal Power Commission (the predecessor to today's Federal Energy Regulatory Commission (FERC)) after the event indicated that 45 percent of utilities affected used their hydropower plants to provide blackstart services, while other utilities used gas or diesel generators to blackstart their systems.[2] Since 1965, six major blackouts have affected about 100 million customers.[3] In 2003, a blackout caused two utilities in Michigan – Consumers Energy and Detroit Edison – to invoke their local blackstart procedures, however neither of them needed blackstart services in the end.[4] Thus, although rare, the availability of blackstart capability is an essential component of a resilient grid as the consequences of a partially or completely deenergized electricity grid would be severe and especially devastating if black start-designated units should fail. During a Black Sky[ii] event, the Unites States will most likely need to restart portions of the electricity grid from blackstart. Because of the significant impact of such an event, blackstart capabilities in the U.S. are very carefully regulated and studied, and blackstart processes and procedures are often exercised by the utilities.

i The North American Electric Reliability Cooperation (NERC) defines a black start capable resource as "a generating unit(s) and its associated set of equipment which has the ability to be started without support from the System or is designed to remain energized without connection to the remainder of the System, with the ability to energize a bus, meeting the Transmission Operator's restoration plan needs for Real and Reactive Power capability, frequency and voltage control, and that has been included in the Transmission Operator's restoration plan." (https://www.nerc.com/pa/Stand/Glossary%20of%20Terms/Glossary_of_Terms.pdf)

ii A black sky event is commonly defined as "a catastrophic event or events compromising electric reliability and the country's collective effort to respond and restore service. This could be a devastating natural disaster, cyber-attack, physical attack, act of war, or a combination of incidences." (https://utc.org/wp-content/uploads/2018/10/Definitions_Final-Version_October-2018.pdf)

Blackstart Technologies and Regulations

Blackstart Technical Components

Blackstart units must have certain characteristics in order to provide appropriate services. Blackstart units must have the ability to start operations without electricity provided by the power grid and be operational within a short starting time. They should also be capable of providing power to the next start units (more on that below). Additionally, blackstart units should have more than one unit to improve redundancy, have ample on-site fuel inventory, and have the ability to vary their output and tolerate frequency variations.[5] Due to these requirements, blackstart generators are often small units that can quickly ramp up and down. This makes the units flexible and able to pair with local loads to create re-energized islands in the initial restart process. The 128 MW Entergy New Orleans Power Station is an example of an ideal blackstart capable power plant – it has seven reciprocating gas units between 15 and 20 MW each that can start without outside electricity supply.

In the United States, gas turbines represent 60 percent of blackstart units registered with the North American Electric Reliability Corporation (NERC). Hydropower units comprise 37 percent of blackstart resources and fossil fuel (combined cycle and diesel) units each are 1 percent of NERC registered blackstart units.[6] Reginal differences exist. In Texas for example, ERCOT's blackstart capabilities are comprised of 28 natural gas units at 13 sites and 13 of the units can be switched to be powered by oil if natural gas is unavailable.[7] NERC's regional reliability organizations maintain a database of blackstart units though it is important to note that there are more blackstart capable units than are registered with NERC (see below). While usually not classified, the location of blackstart resources is often not publicly available. Blackstart units are not necessarily located in each state but are strategically placed throughout various regions. System restoration usually involves multiple blackstart units that energize part of the system to speed up the restoration time.

In addition to blackstart capable units, several other components are necessary to restart all or portions of the electricity grid. For a system to restart from a complete blackout, starting blackstart units is only the beginning. Blackstart generators are usually small and not sufficient to power the entire system, so they will need to energize additional generators, which are usually located in close proximity along a cranking path. The cranking path is one or more transmission lines that provide the electricity generated by the blackstart unit to additional generation units that can then restart to add additional electricity. These next start units are often natural gas plants. To ensure an effective blackstart, two-way communication is critical between system operator, blackstart units, and other regional generation and transmission assets' owners and operators.

Process of System Restoration Through Blackstart Units

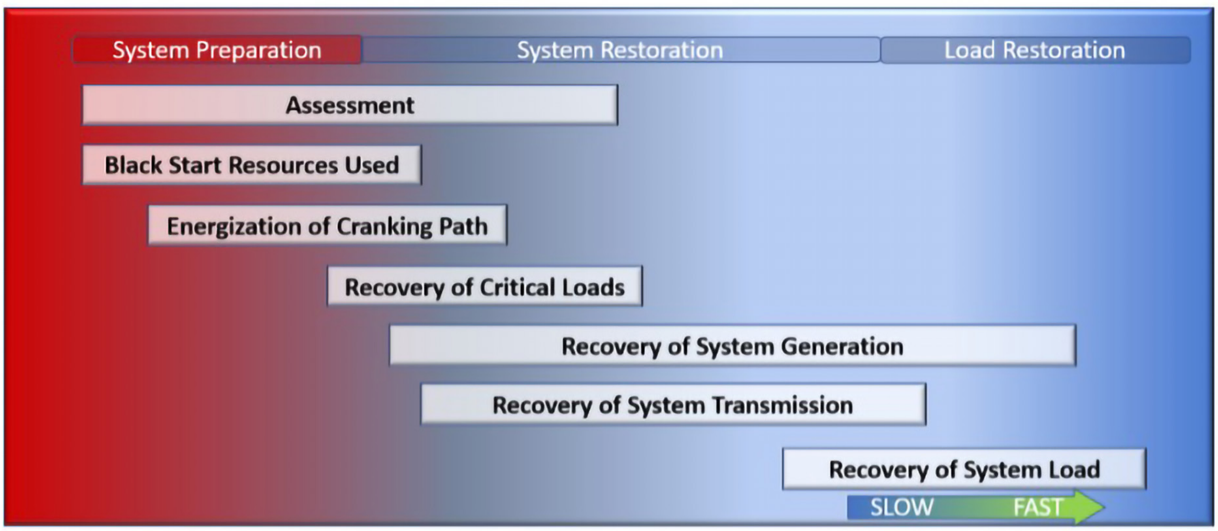
If portions of or all of the electricity grid is deenergized, the process of blackstart restoration generally follows three phases:[8]

After a blackout occurs, the system operator will initially stabilize the still operational parts of the grid, analyze the situation, and assess the proper path to system restoration, which includes identification and availability of blackstart capable units. A critical component of the analysis is understanding "the status of generating units, neighboring systems and tie-lines, and whether any portions of the system are islanded and operational. In addition, the operator must gather information that might help determine the cause of the disturbance, which could prove instrumental in avoiding potential reoccurrences during the restoration process."[9]

During the second phase, or the restoration process, system operators first energize critical loads. These are not only loads that provide critical services (such as hospitals, wastewater and water facilities, and communication facilities), but also loads that continue to support the restoration process of the electric grid, such as transmission facilities, cranking paths, substations, and additional generation facilities. Additional loads to prioritize for restoration include nuclear power plants to ensure cooling pumps are functional. It is important to note when determining critical loads, that some facilities such as hospitals are required to maintain and operate backup power generation (e.g., through a microgrid or diesel backup generator), whereas other facilities such as wastewater facilities might not have those requirements.[10] However, system operators will also have to weigh the availability of fuel at critical facilities with back up generation capabilities.

As more and more power generation units are reenergized and additional load can be serviced, the system gradually moves toward normal operations. This is a finely tuned process, in which the system operator must carefully balance voltage and frequency. Depending on the scale of the initial outage, full system restoration could be a lengthy process requiring a significant level of coordination between the entities involved in the restoration process (see Figure 1).

Figure 1: System Restoration Process Using Blackstart Resources[11]



Standards and Regulations for Blackstart

NERC formulates the technical standards and regulations that pertain to the bulk electric power system (BPS) in the United States, including standards for blackstart units. These are reviewed and approved by the FERC and become mandatory and enforceable after FERC approval. NERC periodically reviews and updates their standards, resulting in different iterations of standards, standards being placed into inactive status, and the creation of additional applicable standards. The following NERC standards[iii] guide blackstart units at the time of writing this report:

Standard Number	Standard Name	Applicability	Description
EOP-005-3	System Restoration from Blackstart Resources	Transmission and generation operators, transmission owners and distribution providers identified in the transmission operators' restoration plan	Provides requirements for restoration plans including identifying blackstart units and their characteristics, blackstart resource testing requirements (frequency of testing, list of required tests), and Blackstart Resource Agreements.
EOP-006-3[iv]	System Restoration Coordination	Reliability coordinators	Requires the reliability coordinators to develop and implement a restoration plan pertaining to their specific region. This plan takes effect when blackstart resources are needed to reenergize parts of the grid until the reliability area is reconnected with its neighboring reliability areas.
EOP-007-0[v]	Establish, Maintain, and Document a Regional Blackstart Capability Plan	Regional reliability organizations[vi]	Requires establishment, maintenance, and documentation of a regional blackstart capability plan (BCP), which is part of the regional system restoration plan (SRP). The plan must include a database of all blackstart units within the region, which is updated annually. The standard also requires that blackstart units are tested and stipulates the testing requirements the blackstart units have to meet.

iii For a complete list of NERC Standards, NERC maintains a one-stop-shop document on its website that includes links to all active and inactive standards, implementations plans, and compliance guidance: https://www.nerc.com/pa/Stand/Pages/USRelStand.aspx. Several CIP standards are also applicable to black start resources (for a list, see https://www.energy.gov/sites/prod/files/2019/05/f62/Hydro-Black-Start_May2019.pdf).

iv Incorporates also EOP-009 – Documentation of Black Start Generating Unite Test Results

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vi NERC divides its area of responsibility, which encompasses the United States, Canada and the northern portion of Baja California, Mexico, into eight regions, each with their own reliability coordinating entity. For more information, see https://www.nerc.com/pa/rrm/TLR/Pages/Reliability-Coordinators.aspx.

The Regional Transmission Organizations and Independent System Operators (RTO/ISO) also have technical requirements for the blackstart units, which vary regarding starting time and fuel inventory:[12]

RTO/ISO	Starting Time	Fuel Inventory (Run Time)
PJM	3 to 4 hours	Over 16 hours or as specified in restoration plan
CAISO	10 minutes	Over 12 hours or as specified in black start agreement
ERCOT	6 hours	72 hours (preferred)
ISO NE	Not mentioned	Over 2 hours (alternative energy resources, including hydro), over 12 hours (other)
NY ISO	90 minutes (gas turbine), 8 hours (steam turbine)	Not mentioned
MISO	1 hour	8-96 hours (50 percent rated output)

Monetary Compensation of Blackstart Units

The costs of maintaining a blackstart unit fall into initial capital costs and ongoing operations and maintenance costs. The capital costs are usually the cost of the equipment added to a power plant to ensure it can provide blackstart services, such as a diesel generator at a hydropower plant. The ongoing costs include maintaining the plant, its blackstart system components, and staff training as it pertains to blackstart procedures.[13] In vertically integrated systems, the costs of blackstart units are approved by states' Public Utility Commissions and then borne by the consumer. In restructured markets, RTO/ISOs have devised three mechanisms to provide compensation for the costs of providing blackstart services: cost recovery, standard payment, or economic payment. PJM, MISO, and CAISO provide cost recovery of incurred capital and maintenance costs. Through standard payment, the ISO New England and the New York ISO provide blackstart units with a flat rate, which is sometimes differentiated by technology, and includes some capital costs, some operations costs, and some NERC CIP compliance costs. ERCOT pays its blackstart units through a competitive process. Most RTO/ISOs place a limit on the duration of the contracts they enter into with blackstart unit providers.[14]

In a report on blackstart adequacy in the United States, FERC and NERC recommended a review of the current compensation mechanisms as they might not be adequate to recover all actual costs[15], which can include costs for extensive staff training, meeting NERC compliance standards, or testing requirements. For example, the Lake Lynn hydropower station in West Virginia, which provides blackstart service to PJM, "earns roughly $51,000 a year in payments for its capabilities but spends about $65,000 a year on regulatory compliance."[16] An additional constraint for blackstart units is the limited duration of contracts, which increases the risk for operators and might prevent them from making investments to enhance the blackstart capabilities of their plants.[17]

The FERC and NERC report also underscored that next start units receive no financial compensation and recommended that RTO/ISOs examine the potential for such compensation.[18] This will be especially important in the coming decades as the natural gas power plants, which often serve as next start units due to their ability to ramp up quickly, are retiring due to economic and environmental pressures (see more below).

The Changing Energy Sector and Its Impact on Blackstart Units

The electricity system in the United States has changed significantly over the past decades and is undergoing further transformation. While the retirement of coal and nuclear power plants does not affect blackstart capabilities since they are not used as blackstart units, the impact of climate change on hydropower, the increased electricity generation from renewable energy resources, the potential retirement of natural gas plants, and the increased deployment of distributed energy resources, microgrids, and batteries will affect blackstart units in various ways.

Effect of Drought on Hydropower as Blackstart Provider

As mentioned above, hydropower plants provide a significant portion of blackstart units, partially because the fuel to operate the power plant – water – is always available. However, the western United States, where hydropower is most prevalent and provides much of the region's electricity, is experiencing extreme drought conditions.[19] The EIA projects that U.S. hydropower generation will decline by 14 percent in 2021 compared to 2020 due to drought conditions. Since 2011, annual hydropower generation in the United States has declined from over 300 billion kWh to 250 kWh (projected for 2021),[20] impacting some plants so severely that they must temporarily suspend operations. In California, for example, the Edward Hyatt Power Plant had to shut down due to low water levels for the first time since it started operations in 1967.[21] As climate change is expected to exacerbate drought conditions over the next decades in many regions,[22] hydropower plants providing blackstart capabilities may be impacted and their operations or capabilities could be diminished, making it necessary to have alternatives available.

The Role of Natural Gas Power Plants in the Future

Driven by low natural gas prices, the increase in renewable energy, and the retirement of coal plants, since the early 2000s the use of natural gas for electricity generation has increased dramatically. Currently, natural gas is the main fuel used for generating electricity in the United States - in 2020 natural gas generated about 40 percent of U.S. electricity.[23] As winter storm Uri highlighted in early 2021, the interdependencies between the electricity and natural gas sectors are critical for blackstart units. The NRG Energy natural gas power plants at Parish and Wharton, for example, include two blackstart units. Both plants were offline for extended periods during winter storm Uri.[24] As climate change increases the frequency and damage of disaster events, the weatherization of natural gas and electricity equipment, especially of blackstart and next start units, will become increasingly important. The future of natural gas is uncertain due to price fluctuations, technological advances, and concerns about the fuel's impact on climate change. As the United States transitions to a carbon-neutral electricity sector and the generation of electricity from renewable energy increases significantly, natural gas plants are more likely to decrease their share in electricity generation. As blackstart units are comprised mostly of natural gas units, and a sizable portion of next start plants along the cranking paths are natural gas plants, a large number of natural gas plants retiring in the future would have significant implications for blackstart and next start units.

New Technological Advances

The electricity generation mix in the United States is changing with the retirement of coal power plants and increased generation from renewable energy. These changes have raised concerns about the declining availability of traditional power plants to provide blackstart capabilities, especially as traditional wind turbines and solar systems are not suitable to provide blackstart capabilities. However, recent technological advances and research into how emissions from electricity generation can be further reduced while still providing blackstart capabilities, may offer solutions. In 2020, ScottishPower Renewables achieved the world's first blackstart using an onshore wind farm. Through virtual synchronous machines technology, the company was able to regulate the frequency and voltage of power from the turbines and reenergize the part of the electric grid that had experienced an outage.[25] However, wind and solar will only be able to provide blackstart capabilities when the wind and sun are available unless they are equipped with an auxiliary power source. Batteries offer another potential option to provide blackstart capabilities without relying on diesel back-up generators. In California in 2020, the Imperial Irrigation District (IID) was the first in the United States to use a 33MW/20MWh lithium-ion battery to start a 44 MW combined cycle natural gas turbine.[26] Siemens Energy has also announced that it will build a battery energy storage system for the Marsh Landing Generation Station in California to provide blackstart capabilities going forward. The battery will be able to provide electricity to restart one natural gas unit at the power plant with three attempts per hour.[27] As many states are contemplating deploying microgrids to enhance the resilience of parts of the electricity grid, potential blackstart capabilities such as batteries could be located within these microgrids to provide more localized blackstart options. In FY20, the Resilient Maryland program administered by the Maryland Energy Administration awarded funding to the Howard County Government Campus, a critical infrastructure facility, to plan a microgrid with a combined heat and power system with black start capabilities.[28] The U.S. Department of Energy and the national labs are continuing their research to better understand the impact of grid modernization and the evolving generation mix on the system's reliability and resilience. This includes considerations about how inverter-based resources can provide a range of blackstart capabilities and potentially serve as next start units.

State Energy Policy and Planning Considerations

State Energy Offices provide direction and planning guidance to state energy policy and programs through State Energy Plans and State Energy Security Plans. Additionally, they often participate in state-wide planning on resilience, climate change, and economic development. Often, State Energy Offices are also the lead state agency for the Emergency Support Function for Energy (ESF-12), and thus responsible for supporting State Emergency Management Agencies during an energy emergency. They also often coordinate closely with and provide input to investor-owned and consumer-owned utilities and state Public Utility Commissions. In all of these functions, it is important for State Energy Offices to consider the impact blackstart units have and how blackstart capabilities can be strengthened, especially as the electricity grid transitions to carbon-neutrality. The following are some policy and planning considerations State Energy Offices can undertake to strengthen blackstart capabilities within their states or regions.

1. **Building and Strengthening Relevant Relationships**
   As mentioned above, while usually not classified, the locations of blackstart resources are often not publicly available. However, State Energy Offices and specifically State Energy Offices that are the lead agency for ESF-12, can discuss pertinent information on blackstart units with the relevant utilities, Public Utility Commissions, and regional reliability organizations. Building regional relationships is especially important because blackstart capable units are not located in each state. Still, while they could be located physically in a neighboring state, they are within a utility's footprint, making the outreach to other State Energy Offices and Public Utility Commissions on blackstart capable units even more important. Discussions can also include monetary compensation considerations as well as the impact of the changing electricity generation mix on blackstart capabilities.

2. **Planning Considerations and Data Needs**
   As State Energy Offices develop and update State Energy Plans and especially State Energy Security Plans, considering the impact of a potential system-wide outage is critically important. This includes an understanding of blackstart capable units currently available and the potential impact of climate change and a transitioning electricity system on those generating units. Hydro generating stations might be impacted by drought conditions that threaten their status as a blackstart capable unit. Natural gas plants, which are either blackstart units or important as next start units along the cranking paths and transmission corridors, might be slated for retirement. State Energy Offices will need appropriate data and risk analyses to fully understand blackstart implications of a changing electricity system.

3. **Including Blackstart Resources and Scenarios in Energy Emergency Exercises and Reviewing Blackstart Units Performance in After Action Reports**
   To ensure that blackstart resources are available when they are needed, it is important to include blackstart resources and scenarios in energy emergency exercises. Building on relationships with RTOs, utilities, and other relevant energy stakeholders, a scenario including blackstart units could facilitate information sharing, understand the availability or lack of availability of blackstart resources in an emergency, examine the regional approach to using blackstart units, and discuss other key considerations around blackstart. Additionally, as after-action reports are developed following energy emergencies, it is important to examine any potential issues that blackstart units were facing (such as during the winter storms in Texas in early 2021) and work with the appropriate entities to address any concerns. While it is often difficult to train for system outages and blackstart capabilities due to the cost and difficulties of powering down parts of the grid, utilities have successfully used digital simulations to train for a blackstart event.

4. **Assessing Resilience of Blackstart Units**
   NERC and RTO/ISOs set requirements for adequate fuel supply for blackstart units. However, states might want to consider if additional requirements for fuel supply (for example by requiring on-site storage of fuel in larger quantities or examining the possibility of using two separate fuels) should be added to especially vulnerable blackstart units. New federal requirements for weatherization of power plants, including blackstart units, were approved by FERC in August 2021 but will not take effect until April 2023. FERC is encouraging utilities to comply earlier with these standards.[29] While regulation of investor-owned utilities lies with state Public Utility Commissions, it is important for State Energy Offices to understand the implications and implementations of the new FERC standards on blackstart units. To ensure that the electricity grid, including blackstart units, are more resilient in the future, the Texas legislature passed SB3, which requires electric generation facilities and certain natural gas facilities and pipelines to weatherize. These new rules will be formulated by the Texas Public Utility Commission, which will specify requirements and fines for non-compliance.[30] In addition to weatherization concerns, cybersecurity considerations might also impact the resilience of blackstart units and should be subject of assessing the resilience of blackstart units.

5. **Understanding Interdependencies Fully**
   As mentioned above, blackstart capabilities rely on interdependent systems, including natural gas, electricity, and telecommunication systems which are all critical components. As these systems are becoming more interdependent, the wholistic planning function of State Energy Offices can provide an understanding of these linkages and provide resources to ensure that critical infrastructure components are adequate for blackstart units. A natural gas plant cannot blackstart without an adequate supply of natural gas or if the ability for the plant operator to communicate with other asset operators is compromised. To address the interdependencies that led to the power outrages during winter storm Uri, the Texas legislature established a new committee that "will identify critical infrastructure sources in Texas and map the state's electricity supply chain, which includes all natural gas facilities and practices required for electric generation facilities to maintain service."[31] Mapping such interdependencies specifically for blackstart and next start units can provide insights into the reliance of those units on other sectors. This should include an assessment of the availability of fuel for blackstart units, which often rely on diesel generators for initial power.[32] While there are requirements for fuel availability on-site (as mentioned above), long-term electricity outages and physical hazards such as flooding or downed trees and power lines might prevent additional diesel deliveries.

As State Energy Offices plan for a clean, reliable, and affordable energy sector, understanding the implications of policy decisions on blackstart capabilities, current challenges, and technical considerations as well as ongoing coordination with the relevant stakeholders will be an important component to ensuring a reliable electricity system.

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