Prepared Statement of Juan Torres
Associate Laboratory Director for Energy Systems Integration
National Renewable Energy Laboratory

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Chairman Murkowski, Ranking Member Cantwell, members of the Committee, thank you for this opportunity to discuss the importance of blackstart and the significant role it plays in ensuring that our power system in the United States continues to be safe, reliable, and resilient.

I am Juan Torres, and I serve as the associate laboratory director for Energy Systems Integration at the U.S. Department of Energy's (DOE's) National Renewable Energy Laboratory, or NREL, in Golden, Colorado. I have been affiliated with federal research and our national laboratory system for more than 28 years. In my current position, I direct NREL's efforts to strengthen the security, resilience, and sustainability of our nation's electric grid. In addition, I am vice chair of the DOE Grid Modernization Laboratory Consortium (GMLC) and team lead for the GMLC's security and resilience team. The GMLC is a partnership of 13 national laboratories to advance the modernization of the U.S. power grid. Prior to joining NREL, I served for many years in various technical and managerial roles at Sandia National Laboratories advancing cybersecurity, energy, and power grid research, most recently as deputy to the vice president for energy programs. Earlier in my career, I also served on the DOE task force that developed a plan to protect U.S. energy infrastructure in response to Presidential Decision Directive 63 on Critical Infrastructure Protection.

What Is Blackstart?

Simply put, blackstart is the ability to restart the power system in the event of a blackout. The blackstart process relies on an established process for coordinating the restarting of specifically designated resources to energize the transmission system, bring on other generators, and get the entire system back up and running.

Throughout my career, I've developed a keen appreciation of the role blackstart concepts may play in the operation of a safe, reliable, and resilient electric grid. That's because the economic and social impacts of a major system outage can be catastrophic. The Northeast Blackout of 2003, for instance, affected some 55 million residents of the United States and Canada. It is estimated to have cost some $6 billion, with at least 11 lives lost. After this event, I oversaw researchers called upon to investigate the cause of the blackout.

From the operator's perspective, blackstart is the fundamental ability to recover from a blackout by systematically bringing up essential parts of the power system *without* having an outside electrical supply available to help. It may include having the ability of a generation unit to remain operating at reduced levels when disconnected from the grid. To restore the generation of electricity after a widespread outage, blackstart configured generators must be started individually and gradually reconnected to each other. The remaining generators not configured for blackstart then synchronize themselves to the blackstart generators until the interconnected system regains full operation and all loads can be served.

In the reality of field operations, however, restoration of the bulk power system from a complete or partial blackout can be an intricate and multifaceted endeavor, fraught with potential technical challenges. To prepare for system restoration, the correct level of blackstart resources must be available at the right locations within the grid so that operators have confidence the set procedures will work as planned and time to full restoration is minimized. History has shown severe weather or other events may cause the simultaneous loss of more than one major grid element, potentially complicating a blackstart restoration. Additionally, the lack of clear, effective, and uniform policies to adequately compensate providers of blackstart resources has been identified as an important missing piece in optimizing blackstart capabilities nationwide.

The evolution of the grid from a system based largely on centralized generation to a more dynamic system with active loads, energy storage, distributed generation, and variable resources such as solar and wind only adds to the complexity involved. The good news is that these new resources, while adding new challenges, also may offer new options to help restore the grid from a blackout. That is, of course, only if the needed blackstart research and development is conducted to make that possible and adequate resources are directed to deploy and operate these new applications.

It is important to note the important role the North American Electric Reliability Corporation (NERC) plays in regulating power restoration. NERC has long-set mandatory reliability standards for Emergency Operations and Preparedness, which include restoration and blackstart procedures. The NERC standards most applicable to blackstart are detailed in sections concerning emergency operations planning, system restoration from blackstart resources, and system restoration coordination. Broadly speaking, these standards require transmission and generation operators to ensure that their plans and designated facilities are technically sound, that control rooms are prepared to use identified restoration resources, and that personnel are appropriately trained and certified in operating principles and ready to effectively coordinate a blackstart restoration process.

Research Needed for Blackstart Capability

While the concept of blackstart is well established, considerable research is needed to ensure that blackstart functionality is appropriately considered as the grid architecture, technology, operations, and generation portfolio continue to evolve. DOE is taking a forward-looking approach and evaluating how a variety of new technologies can be used to provide blackstart capability. This includes an assessment of local energy storage, microgrids, and other distributed energy resources. Technological and operational strategies to raise the detection and situational awareness of potential brownouts and blackouts, and circumventing or mitigating those, is an additional area deserving of research.

In support of the Defense Critical Infrastructure Program (DCIP), which includes U.S. Department of Defense efforts to identify, prioritize, and coordinate the protection of critical Defense Industrial Base assets, DOE will be exploring blackstart needs to support these assets. A spectrum of generation technologies, fuel sources, and grid configurations will be encountered to meet site-specific DCIP needs, underscoring the need for robust technical and operational solutions founded on strong research and development.

Grid Modernization

As a leader of the GMLC, I understand the role that research must play in our broader grid modernization efforts. Toward that end, DOE has invested in GMLC research to increase grid reliability and resilience. One particular project led by NREL, Grid Frequency Support from Distributed Inverter-Based Resources in Hawaii, explored how distributed energy resources can help restore grid stability following major events, such as the loss of a major power plant or major transmission line. Another project led by Los Alamos National Laboratory, titled Extreme Event Modeling, is quantifying the risk of extreme events prior to an occurrence. Recently, DOE awarded several projects focused on resilient distribution systems. One of these projects, called CleanstartDERMS, was granted to Lawrence Livermore National Laboratory and includes partners Pacific Northwest and Los Alamos national laboratories. The goal is to demonstrate the use of distributed energy resources to maintain resilience on the grid to large-scale disruption events. The project will also demonstrate the potential of DER-based microgrids to serve as critical brown- and blackstart-capable resources.

The DOE Office of Electricity Delivery and Energy Reliability recently received budget approval for a particularly forward-looking project called the North American Resilience Model, or NARM. Through this project, NREL and other national laboratories will be collecting data and developing new approaches to plan and operate the grid under extreme events. This is one of the first projects of its kind to take a more complete, all-hazards approach in understanding threats and consequences. The electric grid and other vital sectors such as transportation, gas, and water are highly interdependent. Only through fully understanding these interdependencies will it be possible to plan and mitigate potential risks with analytically driven investment. NARM will look beyond electricity reliability to quantify resilience needs and compare the risk mitigation architecture and actions, including blackstart, for the electric grid—and its vital connected infrastructure.

Renewable Resources, Distributed Energy, and Energy Storage

The expansion of renewable energy technologies such as wind and solar has been considerable in some regions of the country. These technologies are playing an increasingly important role in supplying power to the grid, but we need to learn more about how they may contribute to blackstart planning and other reliability services. Though variable generation technologies such as wind and solar have not traditionally been considered part of the blackstart generation portfolio, when paired with local energy storage, these renewable technologies could be potential assets we can employ to restart the grid after a blackout.

My own research institution, NREL, currently is undertaking blackstart research under the Solar Energy Innovation Network, funded by the DOE Solar Energy Technologies Office. Our lab is working with nine teams around the country. PJM, the regional transmission organization covering 13 states and the District of Columbia, and NARUC, the National Association of Regulatory Utility Commissioners, are leading a team focusing on blackstart applications for solar energy generation with storage. PJM has stated that it is looking into blackstart applications because they are seeing a significant increase in photovoltaic generation and storage in their territory, and they believe these assets may be able to provide system resilience and effective blackstart and system restoration.

NREL likewise is studying several other key aspects of these issues, including an examination of utility experiences with, and known pilot projects for, solar energy plus storage for use in blackstart situations. This work encompasses an assessment of the technical capabilities of photovoltaics plus storage systems and an evaluation of how solar with storage may be able to play anything from a minor role in kick-starting a larger generator to a major role in performing the complete blackstart function as a conventional generator would. Relevant business model and compensation issues are being considered as well.

Additional research is also warranted regarding the role wind power may play in blackstart. With new, more efficient control systems, the output power of wind farms can be constant in the moment, which makes it possible for wind farms to participate in power system restoration. Because of wind variability, however, the actual dispatchable output power may not always be constant. More research is necessary to better understand how to optimize the dispatch of wind farms participating in power system restoration.

Energy storage technologies are currently used in blackstart planning and execution, and their role will likely increase with technology advancements and cost reduction. These technologies are varied, including batteries, flywheels, and pumped hydro systems. Additional blackstart applications for energy storage and other distributed resources are beginning to be seriously evaluated, but more research is indicated to optimize their use.

Microgrids

Microgrids present a great opportunity for America's energy resilience strategy. They offer flexibility, local control, and resilience that the larger grid can't provide alone. And in cases of natural disaster or cyberattack, microgrids can act as energy islands, mitigating outages and quickly restoring power to critical facilities, such as hospitals and military installations. With proper planning, microgrids can also be used to provide blackstart service to distribution and transmission systems; however, while microgrids' benefits are considerable, their deployment has been uneven. High capital cost due to lack of standardization and interoperability, deployment times, and the absence of commonly understood business models are some of the roadblocks slowing their broader adoption.

Researchers at NREL and other national laboratories are engaged in advanced scientific research of microgrids. This research includes everything from fundamental research to evaluation, design, and decision support to improve their cost-effectiveness and efficiency, reduce deployment time, and continue to advance technological innovation. This work to advance microgrids directly supports national grid resilience, security, and modernization goals.

Cybersecurity and Communications

In light of the increasing cyber threat to power utilities, it is important to consider the effects that a large-scale cyberattack may have on system restoration. NERC has developed Critical Infrastructure Protection, or CIP, standards as a risk-based approach to protect the bulk grid from physical and cyberattack. While CIP standards are used to increase security against cyberattacks, we are just beginning to understand the multitude of potential ways cyber-related disruptions may impact system restoration.

To evaluate potential extreme conditions and how utilities will respond, last November NERC conducted its fourth biennial grid security and emergency response exercise, GridEx IV. With 6,500 individuals and 450 organizations participating across industry, law enforcement, and government agencies, GridEx IV was a widely represented, two-day drill, with a separate executive tabletop exercise on the second day. These exercises evaluated response scenarios to malware attacks on grid operations as well as focused cyber- and physical attacks on both generation and transmission facilities. This provided the most comprehensive simulated opportunity to date for critical electricity sector stakeholders to evaluate the effectiveness of their planned responses to cyber- and physical attacks and formulate new and more effective strategies; however, this event does not exercise blackstart from a cyber disruption.

We have come to understand that because potential cyberattacks create many serious hazards across the electric grid, cybersecurity is a primary issue that must be adequately confronted everywhere a potential vulnerability is uncovered. That, of course, includes incorporating cybersecurity into every aspect of blackstart planning and execution. Today, blackstart recovery from a cyber incident is not yet well understood or properly tested. This is an opportune area for research by our national laboratories and others.

With increasingly sophisticated communications tools dominating the way we control today's electric grid, these advanced electronic control mechanisms become even more critical when we need to effectively recover from a power blackout. Here again, these emerging technologies offer both challenges and opportunities as they pertain to blackstart concepts and planning. Intricate communications and control systems demand their own commensurately intricate responses during power recovery conditions. At the same time, SCADA (supervisory control and data acquisition) systems and wide-area measurement systems, along with artificial intelligence technology, could help us achieve self-healing of bulk power systems in the future if we devote the necessary research to this effort; however, it may still be necessary to have some level of manual blackstart capability in the event of a catastrophic cyberattack on the power grid.

Procurement and Workforce Issues

Some of the most crucial needs for improving blackstart functionality across the power grid concern procurement and compensation issues, not only technology. Unlike other ancillary services, blackstart capabilities are generally not procured through a competitive market. And while the conditions for qualification, testing, and deployment of blackstart services are spelled in various reliability plans and business manuals, there are not uniform protocols for determining what needs to be procured and how and when it should be. The poorly defined nature of blackstart service procurement is another area of needed analysis. Furthermore, while growing microgrid, wind, and solar resources may be capable of providing restoration services, they have not been required to meet the existing performance criteria requirements established for more traditional resources.

The utility industry's aging workforce, combined with a limited pool of qualified replacements, may impact our power restoration and blackstart progress as well as our broader grid modernization priorities. According to a survey by DOE, 72% of energy employers report difficulties in finding the right talent. That problem is only compounded given the increasing levels of technical proficiency these jobs are demanding. One result: the loss of trained personnel who are proficient and experienced in blackstart restoration.

In Summary

Our ability to bounce back from threats to the nation's electric grid infrastructure depends on coordinated planning, investment, and operational standards. Additional research is needed to identify the hazards before us and their mitigations. In the end, recovery is not only about shocking the system with energy; it is about conditioning the system in a coordinated way over a specified time to return it to the normal state.

As the power generation system continues to evolve, it will be critical to expand blackstart procedures and testing from not only centralized generation on the bulk power grid but also including support from renewable generation and distributed generation systems, where appropriate. Additionally, we must maintain a highly qualified workforce that is not only educated and trained but also exercised to meet the needs of an evolving power grid.