HVDC Transmission: A National Security and Energy Resilience Imperative

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EXECUTIVE SUMMARY

United States national security is under threat, both domestically and internationally. While this issue traditionally has a purely military connotation, the nature and source of threats have expanded beyond planes, tanks, and ships. Modern security risks now target extensions of those weapons platforms; the electrons and molecules that provide the energy needed to execute essential missions. Energy is not a new consideration in the geopolitical landscape, as it has historically underpinned many conflicts. In recent years, the nexus between energy and national security have come into sharper focus. Department of Defense (DoD) installations, numbering more than 500 across the United States, represent the single largest ratepayer in the country. DoD is truly a unique energy consumer, and not simply due to the size of their energy bills. The missions supported by electricity, the vast majority of which comes from privately owned and operated infrastructure, require uninterrupted service in the face of growing climate, physical, and cybersecurity risks.

Significant weather events are increasing in both severity and frequency, posing serious threats to not only DoD's readiness and continuity of operations, but the lives and livelihoods of the citizens that it is sworn to protect. The rapid escalation of adversarial countries' cyber-targeting critical infrastructure puts domestic facilities and assets at the forefront of global conflict, blurring the lines between public sector and private sector boundaries. While climate and cyber threats expose vulnerabilities in physical energy systems domestically, Russia's invasion of Ukraine has laid bare the fragile nature of a globalized energy supply chain. Each new threat creates or exacerbates a risk to the resilience of the electric grid, undermining the essential military and civilian functions it supports.

Central to this discussion are the tools and methods available to mitigate these risks and ensure the resilient delivery of energy to DoD and the national security functions they perform. The electric grid is undergoing an unprecedented transition driven by the rapid proliferation of renewable energy resources, the electrification of transportation, and the increased automation of grid operation. Bridging the gap between the grid of today and the grid needed to meet this national security imperative will require a reimagining of how electricity is delivered at both a micro and macro-level. By aggregating energy resilience requirements across regions at an Interconnection scale, DoD can leverage the redundancy and resilience of the bulk electric system rather than relying on individual distributed energy resources alone. DoD's climate and energy procurement goals create an opportunity for installation energy professionals to partner with utilities to understand threats to the grid, existing infrastructure planning outside the fence line, and shared local, state, and federal clean energy requirements.

Achieving energy resilience will require physical infrastructure capable of accessing geographically dispersed electric generation resources and delivering them across the country through a process which addresses the diverse needs of DoD missions and the resilience of defense communities that support installations. The status quo of transmission planning and design does not provide the resilience necessary to support national security needs. Existing electric transmission systems are serviceable, but inadequate, in meeting the requirements of installations in the modern threat environment. High Voltage

Direct Current (HVDC) transmission has the unique technical capabilities needed to connect previously isolated sources of electricity to critical customers in every region of the U.S. The enhanced controllability of HVDC provides the operating flexibility required to meet the rapidly changing needs of DoD and the communities that support them. Serving as the backbone of the grid, HVDC can perform as both the extension cord bringing electricity to customers impacted by disruptive events, and the jumper cables needed to restart grids suffering from outages. By harnessing the electricity needed to power the essential facilities, assets, and systems of national security, we can chart a path to a clean and resilient energy future.

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ACRONYM LIST

AC	Alternating Current
AFL-CIO	American Federation of Labor and Congress of Industrial Organizations
BIL	Bipartisan Infrastructure Law
CISA	Cybersecurity and Infrastructure Security Agency
DoD	United States Department of Defense
DOE	Department of Energy
ERCOT	Electric Reliability Council of Texas
GBE	Grain Belt Express
HVDC	High-Voltage Direct Current
IEP	Installation Energy Plan
IIJA	Infrastructure Investment and Jobs Act
ISO	Independent System Operator
kV	Kilovolt
LMP	Locational Marginal Pricing
MISO	Midcontinent Independent System Operator
MW	Megawatt
NOx	Nitrogen Oxide
NY	New York
PJM	Pennsylvania, New Jersey, and Maryland
PM	Particulate Matter
PUC	Public Utility Commission
RTO	Regional Transmission Operator
SOx	Sulfur Oxide
SPP	Southwest Power Pool
U.S.	United States
VAR	Volt-Ampere Reactive
WTI	West Texas Intermediate

SECTION 1. THE ENERGY AND NATIONAL SECURITY NEXUS

The global energy landscape encompasses a variety of coinciding climate, technical, and geopolitical challenges. Society is rapidly transitioning towards clean energy generation, transportation electrification, and the proliferation of internet-connected devices supporting grid automation. Simultaneously, the increased frequency of severe weather events place energy systems at risk, signifying an inflection point. The challenges of globalization, climate change, and evolving energy infrastructure are threat multipliers which expose and exploit cyber and physical vulnerabilities across civilian and defense infrastructure. The near total dependence of national security missions on private infrastructure blurs the lines between government and civilian domains, moving infrastructure threats closer to their military targets than ever before. This foreboding threat landscape serves as a call to action to address vulnerabilities in infrastructure systems as national security imperatives, rather than viewing these infrastructure vulnerabilities as techno-economic challenges.

Domestic Security

"Disruptions in electricity, water, wastewater, communications, and transportation systems that service DOD can degrade readiness and mission capability."

Within the U.S., energy system risks manifest with increasing frequency at the 500+ military installations across the country, as well as in the civilian infrastructure supporting them. As the single largest rate-paying customer in the country for utilities, disruptions in electricity, water, wastewater, communications, and transportation systems that service DoD can degrade readiness and mission capability. The same is true for the critical infrastructure supporting homeland security, public safety, and emergency medical functions, all of which are essential to life saving and life sustaining capabilities. The bulk electric system has become less reliable in recent years as major interruptions to electricity service increased from an average of 1.6 hours per year in 2013-2016 to nearly 4.7 hours per year (an increase of 290%) in 2017-2020.[1] This trend is worrisome; interruptions in electricity service impacts utilities' ability to support both national security missions and emergency services.

International Security

The U.S.'s electric grid and broader energy system's dependence on raw materials sourced from adversarial or politically unstable nations exposes the nation to untenable geopolitical risk. The globalization of supply chains for raw materials, critical hardware, software, and technical components creates yet another dependency risk that is difficult to quantify, and even more difficult to mitigate. Additionally, the intertwined nature of foreign policy and energy resources results in unpredictable volatility. Recent events demonstrate the reality of global energy instability, as foreign adversaries seek the means to conduct asymmetric hybrid warfare using state sponsored technology to attack critical infrastructure to accomplish military objectives.[2]

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[1] Today In Energy, November 2021

[2] Summary of the 2018 National Defense Strategy, January 2018, pages 2, 3

Nation-State Adversaries

Intelligence reports indicate that Russia, China, Iran, and North Korea are actively strengthening cyber capabilities to target critical infrastructure.[3] In June 2021, the U.S. Department of Justice charged four Russian government employees regarding the hacking of energy sector critical infrastructure.[4,5] The Cybersecurity and Infrastructure Security Agency (CISA) followed up this announcement by issuing an alert about looming Russian cyber-attacks designed to cripple critical U.S. energy infrastructure.[6] A December 2015 cyber-attack on a Ukrainian electric utility was the first publicly known case of a successful cyber-attack causing a blackout.[7] Russian actors were able to remotely take control of the utility's industrial control systems, turning 30 substations offline for several hours,[8,9] leaving over 200,000 customers without electricity. In 2016, Russian hackers infiltrated the Ukrainian electric grid and caused yet another blackout. The looming risk of attacks on critical infrastructure was brought into sharp relief following Russia's invasion of Ukraine, which ushered in a new era of threats to the global energy sector's continuity of operations. Curtailments of natural gas needed to generate electricity, rapid changes in electricity interchange between Eastern European countries, and nuclear generation sites put at risk all exposed the consequences of war on global energy stability.

Extreme Weather

> *"The DoD was heavily impacted, with 694 installation facilities damaged in some capacity as a direct result of the storm."*

Extreme weather events are also causing unprecedented impacts to the essential services relied upon by the U.S. Department of Defense (DoD) and civilians alike. In 2021, Winter Storm Uri devastated Texas's electric grid. Nearly 70% of Texans lost electricity with an average disruption time of 42 hours over a five-day span.[10] This outage is the largest single outage in U.S. history caused by a "load shed", an event wherein grid operators are forced to take customers offline due to operating conditions. The DoD was heavily impacted, with 694 installation facilities damaged in some capacity as a direct result of the storm.[11] Every major DoD installation in the state experienced some level of disruption to electricity, water, or communications service during the storm. Climate threats such as Uri are increasing in both severity and frequency, posing serious threats to not only DoD's readiness and continuity of operations, but to the lives and livelihoods of the citizens that it seeks to protect.

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3 Worldwide Threat Assessment of the US Intelligence Community, February 2018

4 Four Russian Government Employees Charged in Two Historical Hacking Campaigns Targeting Critical Infrastructure Worldwide, March 2022

5 Tactics, Techniques, and Procedures of Indicted State-Sponsored Russian Cyber Actors Targeting the Energy Sector, March 2022

6 International Cybersecurity Authorities Issue Joint Advisory on Russian Cyber Threats to Critical Infrastructure, April 2022

7 Invisible Digital Front: Can Cyber Attacks Shape Battlefield Events?, November 2017

8 Analysis of the Cyber Attack on the Ukrainian Power Grid, March 2016

9 Inside the Cunning, Unprecedented Hack of Ukraine's Power Grid, March 2016

10 Winter Storm Uri 2021, October 2021

11 Installation Resiliency: Lessons Learned from Winter Storm Uri and Beyond, March 2021

Volatility

While climate and cyber threats create vulnerabilities to physical systems domestically, Russia's invasion of Ukraine has laid bare the fragile nature of a globalized energy supply chain. The side effects of decreased oil and gas supplies on global markets created, and continues to create, real threats to the health and safety of U.S. allies. The price of West Texas Intermediate (WTI) crude oil—the standard for benchmark oil prices domestically—was $92.81 on February 24, 2022 (the day Russia officially invaded Ukraine).[12] The price of oil skyrocketed over the following two weeks, reaching an all-time high of $123.70 per barrel on March 8. Oil prices peaked on March 8 when the White House announced the U.S. would be releasing a total of 120 million barrels of oil from the Strategic Petroleum Reserve.[13] This event shines a light on the national security risks associated with the inability to sustain adequate levels of U.S. energy independence while supporting allies in a way that reinforces global security and economic stability.

Data Center Resilience

Energy-dependent national security functions extend well beyond physical assets and weapon systems. Government use of cloud-based data storage adds another element to the need for a resilient grid. Prior to the invasion of Russian forces, the Ukrainian Government proactively moved data into cloud-based systems owned and operated by U.S. companies to avert the destruction or compromise of essential information. Currently, US companies are the worldwide leaders in cloud storage accounting for more than 70% of global market share.[14] This presents a security imperative for the U.S. to ensure the resilient delivery of electricity to data centers that make up the backbone of cloud networks. Firm energy dispatch is integral to making this happen, especially as the data center hosts are making commitments to procure clean energy to power these facilities.

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[12] Oil Price Charts, August 2021

[13] FACT SHEET: United States Bans Imports of Russian Oil, Liquefied Natural Gas, and Coal, March 2022

[14] Big Tech Is the West's Surprise Weapon in Competition With Russia, China, August 2022

SECTION 2. DoD ENERGY ASSURANCE REQUIREMENTS

The current approach of installing distributed energy resources at individual buildings on DoD installations is inefficient and does not align with the government's transition to clean energy resources. Developments in interregional high voltage direct current (HVDC) transmission have the ability to change the equation, both in terms of providing the large amounts of power when installations need it, and in ensuring the supplied energy is generated from clean energy sources, independent of foreign influence. Additionally, DoD's climate and energy procurement goals create an opportunity for installation energy professionals to partner with utilities to understand threats to the grid, existing infrastructure planning outside the fence line, and shared local, state, and federal clean energy requirements.

DoD Energy Requirement Process

According to the National Defense Strategy, DoD's primary energy program priority is "to ensure the readiness of the armed forces by pursuing energy security and energy resilience".[2] In 2016, DoD took a major step to address looming energy vulnerabilities by mandating all military installations to create an Installation Energy Plan (IEP).[15] IEPs serve as roadmaps for installations to meet DoD energy efficiency, renewable energy, and energy resilience goals. The 2016 mandate was codified in 2018 and installations were then mandated to "incorporate long-range plans for energy resilience capabilities to ensure available, reliable, and quality power for … critical missions", and to consider cybersecurity requirements.[16] These deliberate steps by the DoD to assess and address energy resilience requirements indicates the broader national security risk to critical infrastructure posed by our adversaries. Domestic military installations are connected to the civilian electric grid, which faces threats from increasingly frequent and extreme weather events, aging and outdated infrastructure, and cyber and physical attacks from determined adversaries. Further exacerbating these threats is the lack of visibility military installations have into their electric utility's operations, leaving bases vulnerable to the aforementioned threats.

Infrastructure Project Backlog

DoD identifies energy resilience requirements through the IEPs mandated by DoD in 2016. These plans are developed by installation energy resilience professionals who interview stakeholders across the installation to determine their individual requirements. Following these interviews, each Department collects the IEPs and prioritizes the recommended remediation projects to address shortfalls in infrastructure availability or grid performance. Typically, project requests exceed DoD's available annual MILCON, ERCIP, and FSRM funding, and it can take multiple years for a project to be selected for funding and execution. The resulting backlog of projects signals the DoD's ineffective means to approach energy resilience requirements at its installations. DoD should instead consider an aggregated approach that increases the potential for attracting third-party funding sources (i.e., utility rate-based financing) to upgrade infrastructure outside the installation fence line instead of attempting to fund every project identified at the installation level with its limited energy infrastructure budget. By aggregating energy

[15] Installation Energy Plans, March 2016

[16] Installation Energy Plans - Energy Resilience and Cybersecurity Update, May 2018

resilience requirements across regions at an Interconnection scale, DoD can leverage the redundancy and resilience of the bulk electric system rather than relying on individual distributed energy resources.

Electricity Demand

Representing DoD installation electricity needs as a single load results in a requirement for more than 25 MW per installation. Siting clean energy generation resources with such capacity, either within or near installation boundaries, is difficult since most of DoD's land is already designated for specific uses (e.g., training). In some instances, installations can partner with their electricity provider to build a fossil fueled power plant capable of meeting the large energy requirement during grid outages, though installations may still lack an existing path to solve their energy needs and meet carbon free energy climate objectives. One option for meeting the high electricity demand for an installation with clean energy is to connect installations directly to renewable generating sources through long distance interregional transmission lines. Removing the boundaries of geographic proximity allows for project developers to build large, clean energy sources sufficient to meet the installation's electricity demand.

Electricity Supply Duration

"DoD could rely on a utility to provide highly reliable power in any contingency situation using flexible HVDC transmission to provide access to diverse, reactive power."

In addition to substantial capacity requirements, DoD installations are required to maintain a minimum of 7 days of emergency backup power to sustain critical missions. Currently, DoD generally relies on diesel generators for contingency electricity in the case of a grid outage to meet this requirement. As evident during Hurricane Maria,[17] supplying fossil fuels to an area during a sustained regional electricity outage proves difficult to maintain for longer durations. Additionally, most DoD missions with large electricity requirements do not have a constant demand for electricity. This inconsistent demand can make it difficult for the DoD to financially justify installing power plants near the installation to provide electricity on an as-needed basis. This inconsistent electricity demand also presents challenges for existing alternating current (AC) transmission systems that require load to be known in advance in order for grid operators to secure the necessary generation capacity to support it. Rather than depending on expensive, centralized power plants to satisfy its energy requirements, DoD could rely on a utility to provide highly reliable power in any contingency situation using flexible HVDC transmission to provide access to diverse, reactive power.

National Electricity Availability

DoD energy requirements extend beyond its installations' boundaries because its missions rely on civilian infrastructure outside installation fence lines. These pieces of infrastructure must be powered simultaneously in order to successfully defend the nation. Some portions of DoD missions cannot be relocated and therefore require power to those fixed locations. Due to geographic limitations and the interconnected nature of the existing AC transmission infrastructure, installations are not always able to

[17] Relief Effort In Puerto Rico Drags, Fuel Shortages Are Monumental, September 2017

source power from another region. This was demonstrated during Winter Storm Uri in Texas when the absence of interregional electricity transfers impacted service to nearly every installation in the state and left Fort Hood with a $30 million electric bill for February 2021.[18] Increasing the number of HVDC transmission lines across the country would enable grid operators to route power to critical areas and ensure electricity remains powered when DoD missions are operating.

Energy Resilience in Federal Policy

DoD took several proactive steps to codify the importance of energy resilience to mission assurance, starting with DoD Directive 4180.01 to establish the need to enhance the power resiliency of installations.[19] This preceded the 2018 National Defense Authorization Act (NDAA) which defined energy resilience in law, making it a centerpiece in DoD planning. Additionally, section 215A of the Federal Power Act describes Defense Critical Electric Infrastructure (DCEI) to establish the role of private utilities to provide this electricity services to defense installations. These policy actions provide a foundation to support the energy needs of national security, but they must be expanded on by agencies such as the Federal Energy Regulatory Commission (FERC) to include a comprehensive strategy for resilient transmission systems.

[18] Winter Storm Uri Spotlights Gaps in Military Base Preparedness, March 2021
[19] DoD Directive 4180.01, April 2014

SECTION 3. HVDC'S UNIQUE VALUE

Despite the grid's central role in securing the energy future, it is increasingly vulnerable to both manmade and natural disasters due to age and deferred maintenance. The Department of Energy's (DOE's) 2015 Quadrennial Technology Review indicated that 70% of the transmission lines in service across the grid are 25 years or older.[20] Substantial investment is needed to address these physical and operational shortfalls, but the status quo will not suffice. Transmission infrastructure is the essential link between consumer demand for electricity and the supply from generation sources distributed across the country. The energy needs of the DoD are geographically diverse and require access to electricity regardless of operating conditions. HVDC transmission provides the features needed for a resilient grid that supports national security and harnesses the full potential of advanced energy resources. As the nation transitions to a clean energy economy,[21] the existing transmission system will need to evolve to match the capability and capacity of regionally concentrated generation sources while continuing to provide electricity to the entire nation. The U.S. transmission system must become more responsive in order to provide a greater degree of control over electricity flows, deliver generation from previously inaccessible regions, protect against evolving grid threats, and reduce supply chain risk. A grid with HVDC as its backbone allows for the integration of disconnected markets, brings new energy resources to the table, and supports critical loads by directing power exactly where it is needed with a level of certainty essential for national security requirements.

HVDC has three unique technical capabilities that directly contribute to energy resilience:

- **Controllability.** The speed and flexibility to route electricity flows based on changing conditions.
- **Infrastructure Efficiency.** Longer spans between substations and higher voltage ratings.
- **Frequency Stabilization.** Facilitates power transmission between unsynchronized systems.

HVDC capabilities allow for six key infrastructure system benefits:

- **Outage Protection.** Fewer customer outages due to capacity or demand fluctuations.
- **Energy Diversity.** Improves access to geographically dispersed and variable output generation.
- **Inertial Stability.** Power flow control independent of the balance between generation and load.
- **Interregional Resilience.** Enables emergency exports and imports between grid regions.
- **Black Start Support.** Provides stability during delicate load balancing to restart disrupted grids.
- **Enhanced Supply Chain.** Reduces reliance on fuel and components from adversarial nations.

The relationships between technical capabilities and system benefits are outlined in Figure 1.

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[20] Quadrennial Technology Review 2015, 2015, Chapter 4

[21] What is U.S. electricity generation by energy source?, March 2022

		System Benefits					
		Outage Protection	Energy Diversity	Inertial Stability	Interregional Resilience	Black Start Support	Enhanced Supply Chain
Technical Capabilities	Controllability	✓	✓	✓	✓	✓	
	Infrastructure Efficiency	✓	✓		✓		✓
	Frequency Stabilization	✓	✓	✓	✓	✓	

Figure 1. HVDC Technical Capabilities and System Benefits

Technical Capabilities and Benefits of HVDC

HVDC transmission assets possess physical attributes that provide operational benefits to the Bulk Electric System at the local, regional, and national level. Each technical capability addresses one or more causes of grid disruptions related to system stability, infrastructure availability, or generation resource adequacy. Reducing the frequency, severity, and overall risk of outages is essential to meeting the energy requirements that support national security. Three HVDC capabilities are outlined below, including the system benefits they provide.

Controllability

> *"HVDC allows operators to change the direction of power flows almost immediately while converter stations provide a frequency buffer to sudden voltage fluctuations."*

Power flow across HVDC transmission lines are controllable down to sub-second intervals, allowing system operators to match the dynamic nature of consumer demand. This is especially relevant during periods of high variability associated with extreme events when generator availability changes quickly if facilities go offline, high-demand energy customers unexpectedly lose connectivity, or impacts to infrastructure require the rerouting of electricity to sustain system balance. Non-HVDC systems are limited to a more reactionary means of grid balancing, using static electricity flows and adjusting generator output, or disconnecting customer loads. Instead, HVDC allows operators to change the direction of power flows almost immediately while converter stations provide a frequency buffer to sudden voltage fluctuations. This capability supports DoD missions that rely on multiple installations, or facilities that have substantial load requirements but are not physically co-located, even spanning multiple states. The ability to redirect power flows between grid systems is vital. The benefits of controllability include:

- ***Outage Protection.*** HVDC transmission lines cut down delays in operator reaction time to system changes by enabling them to control reactive power—volt-ampere reactive (VAR)—and immediately provide precise amounts of support to the bulk electric power system. By limiting delays in voltage regulation, which can often take several minutes to address with current infrastructure, HVDC lines improve the ability for operators to control the system's balance and reduce outages across the system.

- ***Energy Diversity.*** HVDC transmission systems make it possible to connect large load centers with the highest quality renewable energy areas in the US. When a blend of inverter-based resources such as wind, solar, and energy storage are combined, the generation profile on an HVDC system looks more like a conventional baseload production profile than an intermittent renewable energy source.

- ***Inertial Stability***. Reactive power adjustment reduces the dependence on firm dispatch of traditional thermal generation plants in favor of the more responsive and directly controllable HVDC converter station. Converter and rectifier stations act as the translator between alternating and direct current systems, ensuring electricity can pass from one system to the other. These stations produce or consume reactive power depending on what is required by the grid operators to balance the voltage and frequency of the grid.

- ***Interregional Resilience.*** Establishing ties between grid territories creates access to new generation resources and provides more flexibility during periods of constrained operations to support resilience.

    - HVDC transmission enables system operators to send specified amounts of power bidirectionally, either toward or away from customer demand. Since the flow of electricity is controllable along the power line, system operators get immediate feedback that power is delivered to selected locations.

    - HVDC transmission lines excel in their ability to efficiently connect generation sites located hundreds of miles away from the load centers they support. The Grain Belt Express transmission line, for example, begins in southwest Kansas and travels nearly 800 miles to Indiana. As a result, the line passes through, and delivers electricity to, four grid balancing authorities, including the Associated Electric Cooperative, Inc, and three of the largest power marketers that make up America's electrical grid: Southwest Power Pool (SPP), Midcontinent Independent System Operator (MISO), and PJM Interconnection (PJM).

- ***Black Start.*** Restoring a disrupted grid using a small number of generators and predetermined transmission "cranking paths" requires very delicate load balancing. HVDC's ability to reroute power quickly is ideally suited to supporting rapid changes in critical load requirements while providing flexibility on the transmission system.

Infrastructure Efficiency

Transmission infrastructure requires a large amount of land to transport power from generators to end consumers. Efficient land use is emphasized to meet increasing customer demand. HVDC can transmit up to three times the voltage of an AC transmission line with lower clearance requirements between power lines and nearby objects (e.g., trees or buildings). This reduces the overall amount of land needed to achieve the same energy benefit, preserving more land for its primary use. Land efficiency also supports a DOE solution to addressing the gap between load demand and clean energy generation by increasing the geographic area in which power supply can be balanced on the grid.[22] Long distance interregional HVDC transmission lines do just that. Many DoD installations are located in remote areas, including terrain that is more challenging to install grid infrastructure and locations that are dependent on a limited number of sites. Maximizing the efficiency of limited grid assets is fundamental to reducing the risk of outages. Additionally, sourcing components, either domestically or from U.S. allied nations, will mitigate the risks of adversarial nations seeking to disrupt military capabilities by compromising grid components. Infrastructure efficiency supports several benefits:

- ***Outage Protection.*** Interactions with vegetation and other structures is the most common cause of outages and HVDC power lines must separate their lines from items that may cause disruptions in order to avoid electrical shorts. The reduced footprint and shorter standoff requirements associated with HVDC allows for fewer points of potential disruption and easier vegetation management than traditional systems.

- ***Energy Diversity.*** Interregional HVDC transmission efficiently realizes clean energy deployment by allowing generation sites to reach economies of scale.

    - **Technology Integration.** Using an HVDC system would enable large, concentrated sources of generation to be distributed across the grid while avoiding many of the issues currently associated with larger transmission networks. Increasing transmission system infrastructure with HVDC would provide the backbone to deploy the clean energy needed to keep pace with electrification as fossil fuel generation is retired.

    - **Distribution of renewable energy generation.** HVDC transmission systems allow for generation sources to be hundreds of miles away from the loads they serve, enabling the clean energy resources available in the U.S. Southwest and the Great Plains to be directed to any region across the country. HVDC regional connectivity is especially beneficial for addressing regional misalignment of wind and solar resource availability and electricity consumption patterns of consumers (i.e., wind and solar generate more energy when consumers demand less and consumers demand more when wind and solar produce less).

- ***Interregional Resilience***. HVDC transmission systems increase the diversity of generator types, as resources can be directed to any region, provided there is a transmission corridor available for the new power lines. Creating an interregional supply of power would increase the resilience of the grid to regional capacity shortages and allow access to more diverse sources of generation.

- ***Enhanced Supply Chain.*** The components required for AC system equipment have become commoditized, and many are sourced from adversarial nations. Similarly, supply chains and shipping

[22] Confronting the Duck Curve: How to Address Over-Generation of Solar Energy, October 2017

logistics from geopolitical adversaries continue to operate slowly and can result in delays of equipment.

- **Reduction in repair and replacement times.** Supply chain constraints and long-lead times for specialized, custom components delays construction of new infrastructure and slows restoration efforts following major events.
  - HVDC systems require far fewer transformers and other commodity equipment than traditional AC transmission since they can span much longer distances between substations. In the event of maintenance or replacement being required, there is a shorter lead time to manufacture and replace components.
  - HVDC transmission systems have a single phase. This allows them to carry the same amount of power as AC systems with only a third of the power lines and with less components that are vulnerable to manmade and natural disasters.
- **North America and European Suppliers.** Components are available from North American and European suppliers. Fewer components sourced from adversarial nations and fewer sites to repair have a substantial positive impact on national security.
- **Fuel Supply Chain.** The ability for the transmission system to be less reliant on a high percentage of fossil fuel generators and concentrations of certain fuel types (i.e. natural gas in the Northeast U.S.) reduces the vulnerability to fuel supply chain disruptions.

- ***Cybersecurity Benefits.*** The ability of adversarial nations to compromise critical Information Technology (IT) and Operations Technology (OT) systems used to operate the electric grid are a significant threat. Utility industry officials indicated that OT cybersecurity is painful, primarily due to the size of the "Attack Surface Area,"[23] indicating the high volume of network-connected devices on energy systems. HDVC's reduced infrastructure requirements can reduce attack surface area by requiring fewer total substations and associated points of entry to disrupt the system. Additionally, security vulnerabilities stemming from components manufactured in adversarial nations, highlighted by the U.S. seizure of a Chinese-built transformer in 2019 reinforce the security value of HVDC components which are largely manufactured in U.S.-allied countries.[24]

Frequency Stabilization

A hallmark of traditional grid stability is the need to maintain frequency across large geographic areas with minor frequency variations marking the difference between reliable service and outages. HVDC brings the ability to connect grid systems without the requirement to match frequency. This, coupled with the ability to span hundreds of miles between capacitor stations, results in fewer barriers to connect

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[23] Biden Executive Order on Power System Cybersecurity Leaves Critical Operations Vulnerable, Experts Say, July 2022
[24] U.S. Seizure of Chinese-Built Transformer Raises Specter of Closer Scrutiny, May 2020

across regional systems. Additionally, generation facilities can come online without first requiring local synchronization, a significant capability for renewable resources that might otherwise need converters or remote dispatch to deliver capacity. Stabilization is especially important to the DoD installations located at or near the grid "seams" between balancing authorities, placing a high importance on this capability.

"Stabilization is especially important to the DoD installations located at or near the grid 'seams' between balancing authorities"

- ***Outage Protection.*** Frequency instability events can cause unexpected outages to occur in systems that deviate too far from their required range. In the case of Winter Storm Uri in Texas, the system frequency dropped below the threshold of 59.4Hz for more than four minutes, indicating that "the grid was within minutes of a much more serious and potentially complete blackout."[25] HVDC would have allowed for more generation resources to support the capacity shortfall and avoid outages.

- ***Energy Diversity.*** The geographic expanse of the U.S. prevents connecting alternating currents as the system would be too large to synchronize. HVDC would enable clean power located in certain parts of the country to be sent across the country, reducing or removing constraints where grid operators are unable to access diverse energy resource types due to their location.

- ***Inertial Stability.*** The ability of HVDC transmission systems to provide virtual inertia also allows inverter-based technologies, such as wind and solar, to be paired with HVDC to sustain and even improve the stability of the grid due to the increased levels of control.

- ***Interregional resilience.*** The lack of frequency in HVDC allows transmission systems to cover large distances without multiple substations or other equipment in short intervals to maintain stability and control. This capability enables clean power sharing between the three North American interconnects without needing to first synchronize the systems.[26] In addition to sharing power, HVDC systems could allow for system operators to control frequency by injecting power from geographically isolated locations without risking the stability of a local system.

- ***Black Start Support.*** During times of significant disruption, reconstituting grid services using a small number of energy "islands" created by specialized generation sites requires the same frequency synchronization as a large, fully operational system. However, the balance is more volatile owing to the comparatively small amounts of capacity and the impact of sudden changes in load. HVDC would provide the ability to rapidly add or remove generation units without the need for synchronization.

The capabilities described would each provide substantive benefits to the resilience of electricity service to DoD installations. More importantly, the aggregated impact of HVDC transmission supporting the Bulk Electric System across the U.S. would benefit national security as a whole.

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[25] The Timeline and Events of the February 2021 Texas Electric Grid Blackouts, July 2021, Page 27

[26] U.S. electric system is made up of interconnections and balancing authorities, July 2016

SECTION 4. COST EFFICIENT ENERGY RESILIENCE

Energy independence and energy security are directly correlated, with a shared need for resilience. Transmission, specifically HVDC, is the backbone needed to ensure that resilient, clean energy is delivered to meet the needs of DoD. The United States excelled in advancing energy independence during the past several decades by increasing domestic fossil fuel production. Still, that has not insulated the U.S. from global energy instability and the resulting price shocks. Energy independence during the current transition to a clean energy economy is a cornerstone of national security today and in the future.

The anticipated surge in economic investment spurred by the 2021 Bipartisan Infrastructure Law (BIL) places transmission investment at the center of reducing the number and duration of power outages that cost the U.S. economy up to $70 billion annually. BIL funding places a heavy emphasis on the importance of evaluating the relative cost and benefits of different transmission infrastructure as part of these investments. It is estimated that 140,000 miles of transmission lines will have to be replaced before 2050, as their average lifespan is supposed to be about 50 years.[27]

A Proven Technology - The Pacific Intertie

Interregional HVDC lines will address current and looming infrastructure vulnerabilities, and they do so with proven technology. HVDC transmission was first introduced in the US in 1961 with the Pacific Intertie, which includes an 842 mile HVDC line connecting generation in northern Oregon to Los Angeles.[28] The Pacific Intertie line was built to match regional peak load needs, harness untapped economic value from clean energy generation, help balance electricity flow, and provide lower costs of electricity. In fact, one of the inspirations for the Intertie stemmed from national security concerns and competition with Russian adversaries. The administrations of Presidents Eisenhower and Johnson were concerned with Russia gaining geopolitical advantages over the U.S. following the DC interconnection between Russia and Sweden several years earlier.[29] In the years since, the Pacific Intertie has been described as a critical lifeline providing affordable, reliable, and renewable hydropower during a time of unrelenting energy demand for customers.[30]

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[27] Why the U.S. is Struggling to Modernize the Electric Grid, August 2022

[28] Coast Power Grid Pressed by Udall, December 1961

[29] Power Grid Plan Goes to Congress, June 1964

[30] The D.C. Intertie: A Lifeline to California and An Engineering Marvel, September 2020

Affordable Electricity

> *"HVDC lines provide economic and energy benefits during normal operating conditions and extreme weather events by opening access to the lowest cost domestic renewable resources"*

A regional, interconnected HVDC grid has critical implications beyond the matching of supply and demand. HVDC lines provide economic and energy benefits during normal operating conditions and extreme weather events by opening access to the lowest cost domestic renewable resources in the U.S. and overcoming both the physical distance and grid congestion that is currently trapping these resources from being unlocked. The direct economic benefits of large scale HVDC lines are apparent through locational marginal pricing (LMP), which reflects the price of electricity and the cost of congestion and losses at points across the grid.[31] These prices are dynamic, can be influenced by several factors, and provide insight to the geographic areas in which significant imbalances exist in customer demand and the presence of local generation capacity.

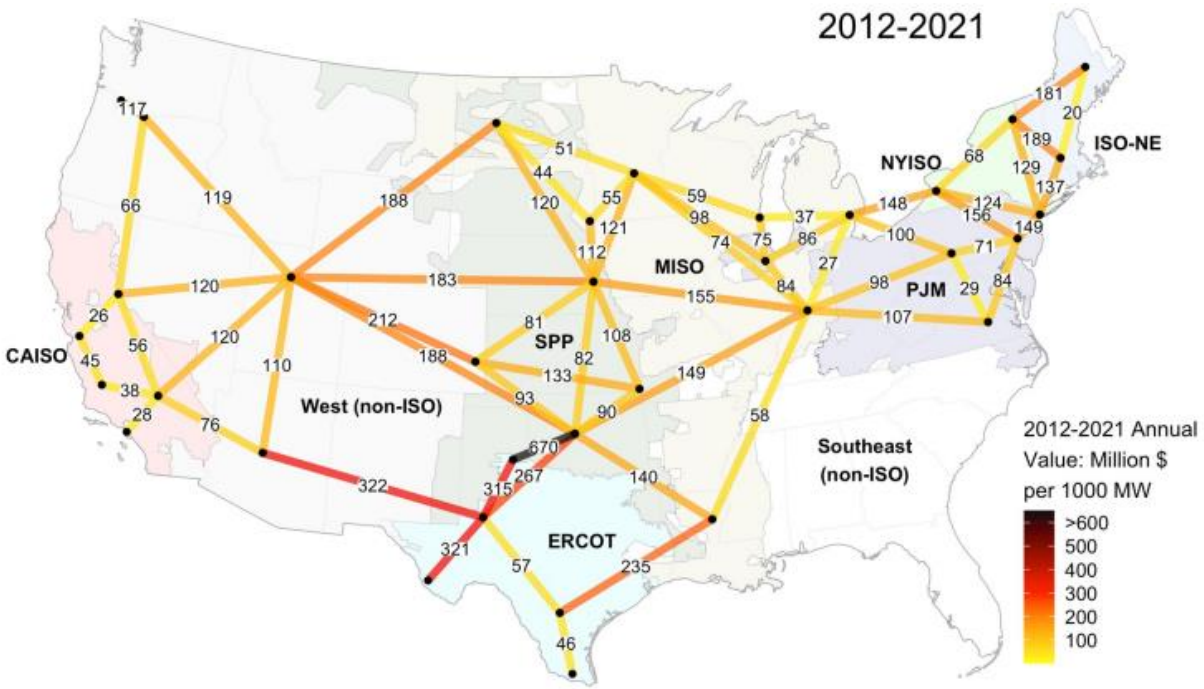

Figure 2. Marginal Value of Transmission in Relieving Congestion ($/ GW-year)

Lawrence Berkeley National Laboratory's (LBNL) Transmission Value study showcases the economic need for interregional transmission buildout.[32] Figure 2 shows the average extra costs consumers are paying each year due to transmission congestion in millions of dollars.[30] The top interregional line between ISO-NE and NYISO shows that consumers are paying an extra $181 million a year because of transmission costs, as compared to the regional line with NYISO where consumers are paying an extra $68 million a

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[31] Locational Marginal Pricing, September 2020

[32] Empirical Estimates of Transmission Value using Locational Marginal Prices, August 2022

year. This comparison is a microcosm of transmission costs across the country. The common trend is that interregional lines have higher values because they see more congestion.

The National Renewable Energy Laboratory released a study showing every $1 invested in interregional transmission can have as much as $2.57 in long-term benefits.[33] Increasing interregional HVDC lines would save consumers money by increasing opportunities for transmission and connecting clean energy generation sites with load demand centers. As such, two locations could have the same average value, but could still derive benefits from transmission if their high- and low-priced hours occur at different times from each other.

Resilience Through Regional Connectivity - Winter Storm Uri Case Study

Looking at LMP from a single weather event, Figure 3 demonstrates prices of electricity on the morning of February 15, 2021 at the height of Winter Storm Uri.[34] The shaded areas of Figure 3 represent the PJM, SPP, MISO, and ERCOT service territories during a time of peak weather-driven demand. The level of pricing variance between balancing authority footprints demonstrates the need for HVDC transmission ties. An HVDC line connecting MISO to PJM during this event would be capable of reducing both the number of outages and the cost of service experienced by customers impacted by this event. Bi-directional flow of electricity during periods of rapid change in customer demand would relieve gaps between capacity and load by quickly redirecting power flows to impacted areas with limited access to local generation. Forced outages and resource shortfalls caused by cold weather impacts to fuel delivery systems could be offset by resources flowing from regions outside the area of impact. By allowing access to lower costs of electricity through interregional transfer, the sharp LMP "seam" between MISO and PJM would be alleviated, saving customers millions of dollars in avoidable charges.

Figure 4 highlights access to low-cost electricity by displaying the price of power across ERCOT and its surrounding Regional Transmission Operators (RTOs) from February 12-20, 2021. With the exception of ERCOT, each of the RTOs used interconnected transmission networks across territory boundaries to weather the storm of high electricity prices caused by Winter Storm Uri. Even SPP South and MISO South Entergy, the two closest RTO subregions to ERCOT, did not see their prices nearly as high as the ERCOT service territory, further demonstrating the power of regional, interconnected HVDC lines. Michael Goggin, Vice President of Grid Strategies, sums up this need by saying "[W]eather systems can be large, but they're not that large. If you make the grid large enough and strong enough, you can use imports from other regions [to minimize negative impacts]."[35] Despite the severe weather in Texas and the Midwest, the broader U.S. was not impacted.

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[33] The Value of Increased HVDC Capacity Between Eastern and Western U.S. Grids: The Interconnections Seam Study, October 2020

[34] Transmission Makes the Power System Resilient to Extreme Weather, July 2021

[35] New Transmission can Prevent Power Outages During Extreme Weather — and Save Tons of Money, July 2021

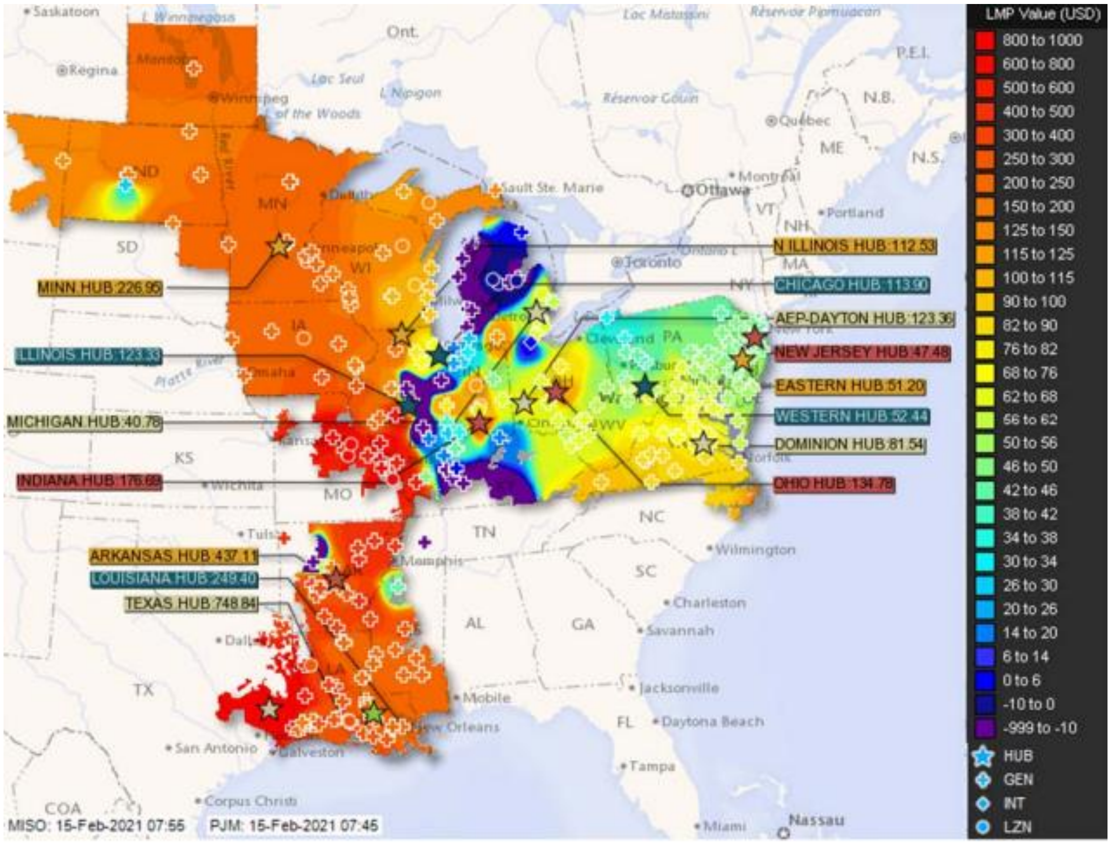

Figure 3. Power Prices the Morning of February 15, 2021

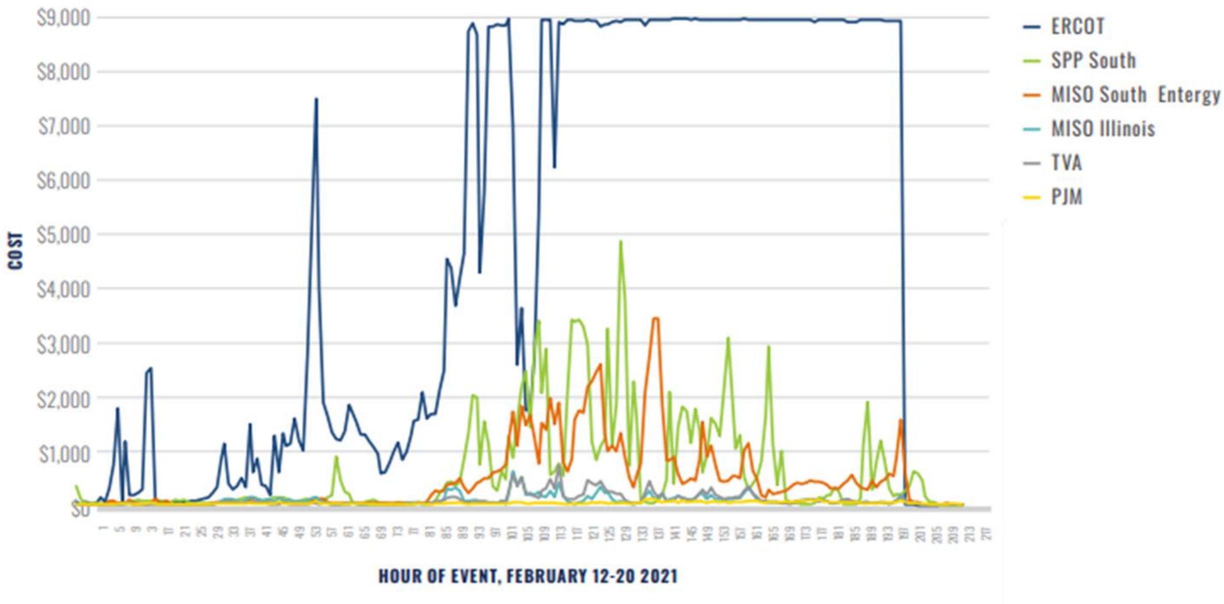

Figure 4. Power Prices by RTO During Winter Storm Uri[34]

As extreme weather events increase in frequency, individual regions will be better prepared to handle extreme weather events if they are interconnected. SPP experienced such benefits during Winter Storm

Uri in February 2021. A significant number of generators in SPP's service territory went offline, forcing SPP to issue load shedding requests. SPP's load shedding was not as severe as predicted due to interconnections with surrounding RTOs and balancing authorities. Such interconnections allowed necessary electricity imports into the SPP South territory, which kept electricity flowing to areas of high demand. This, in turn, helped SPP meet demand and reserve obligations during most of the cold weather event.[36] Rather than SPP asking its customers to decrease their vital energy use, customers were able to keep their heat on, refrigerators running, and water flowing during Winter Storm Uri. SPP stated, "[t]ransmission, both within and outside SPP, proved critical and beneficial in avoiding longer controlled interruptions of service."[20] Narrowing in on transmission's role in preventing electric outages, SPP's report continues to say, "an increased focus on improving the transmission system [is] critical to decrease the possibility of further controlled interruption of service to customers."[20]

[36] A Comprehensive Review of Southwest Power Pool's Response to the February 2021 Winter Storm, July 2021

SECTION 5. HVDC BENEFITS AT ALL LEVELS

Successful transmission development requires coordination across a variety of stakeholders. Stakeholders range from individual landowners to various agencies across the federal government, and each stakeholder stands to gain from the deployment of HVDC transmission lines. The Federal Government can be the most complex stakeholder to engage with, due to its size and the diversity of missions across agencies, but offers a glimpse into the flexible role HVDC can play to improve resilience for any electricity customer.

Department of Defense

The DoD's mission is to provide adequate military forces needed to deter war and ensure the nation's security.[37] HVDC lines will directly benefit DoD's mission assurance, starting with regional resilience achieved through an interconnected grid. Local outages referenced throughout this paper demonstrate the consequences of a compromised electric grid to civilians and defense installations alike. Establishing new pathways to access energy in support of critical customers is foundational to achieving a level of resilience that supports communities during potentially disruptive events. The Grain Belt Express project connects energy resources in four balancing authorities, spanning 23 states, which are home to more than a quarter of DoD's entire footprint. The GBE will allow installations in those states to access new generating assets as part of regional interchange (Figure 5).

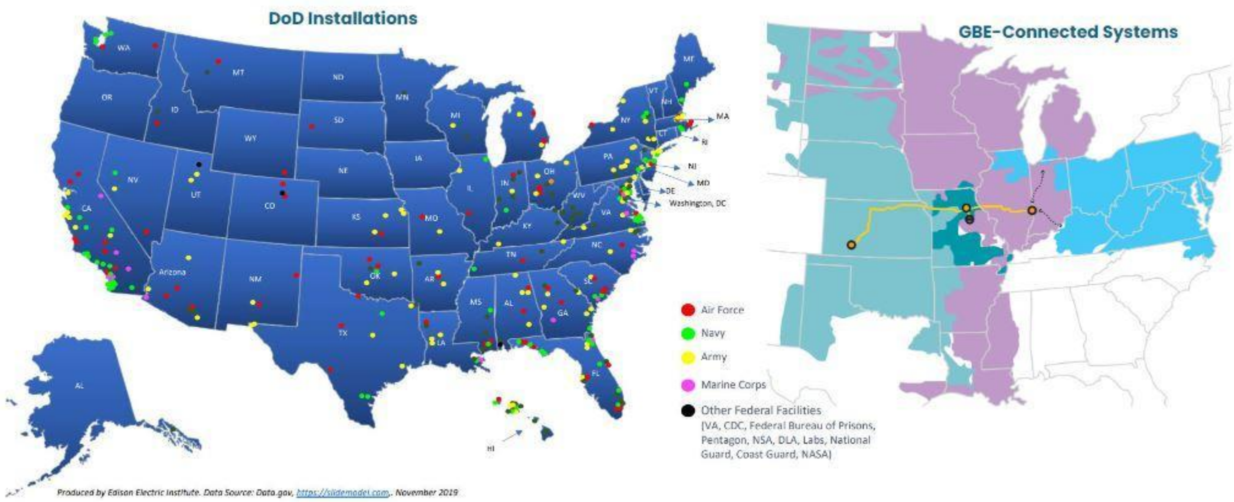

Figure 5. Regional Resilience Provided by Grain Belt Express[38,39]

[37] U.S. Department of Defense - About, August 2022

[38] Issues and Policy - Department of Defense & Federal Government, August 2022

[39] Grain Belt Express, August 2022

Department of Energy

As shown in Figure 5, military bases are not the only beneficiaries of increased access to energy resources. The communities that surround DoD installations and large customer centers in cities throughout the region also see the cost and resilience benefits of connecting wind resources in Kansas to load centers in Illinois. This aligns with the DOE's top three priorities: combating the climate crisis, creating clean energy union jobs, and promoting energy justice. Each of these priorities can benefit from HVDC transmission build-out.[40]

- ***Combating the Climate Crisis.*** Investment in interregional HVDC transmission is integral for DOE to uphold its commitment to creating an "equitable clean energy economy and cement America on a path to net-zero carbon emissions by 2050".[39] DOE estimates that more than 930 GWs of clean energy are ready for development, but are held up because of lack of transmission.[41] If deployed, this clean energy generation would help the U.S. economy achieve 80% clean electricity, meeting the Biden administration's goals for a decarbonized economy.

- ***Creating Clean Energy Union Jobs in Communities.*** The construction of HVDC transmission creates multi-million-dollar potential for community benefits. Such benefits may be enhanced when a developer chooses to use union labor to build the line. Invenergy Transmission's Grain Belt Express transmission line is endorsed by the International Brotherhood of Electrical Workers, the Missouri AFL-CIO, and Laborers' International Union of North America Local 338. Several thousand jobs will be created across the footprint of this project, 1,500 of which stem from the construction period in Missouri.[42],[43] These jobs contribute to economic growth through buying power and increased tax revenue for local governments.

- ***Promoting Energy Justice.*** HVDC transmission has the potential to promote energy justice in historically disadvantaged communities, with the goal of achieving equity in both social and economic participation in the energy system. As an example, Clean Path NY promotes energy justice through the transition to clean energy by creating a $270 million community investment fund, governed by local stakeholders, with an emphasis on representation from historically disadvantaged communities.[44] New York's fossil fuel generation sites are disproportionately situated in low-income neighborhoods, leading to adverse health impacts, such as asthma and chronic illnesses, for the surrounding communities due to increased NOx, SOx, and PM levels. Clean Path NY creates a mechanism for these plants to be shut down in favor of clean energy sources elsewhere.

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40 U.S. Department of Energy, August 2022
41 Queued Up… But in Need of Transmission, April 2022
42 Kiernan: Grain Belt Express offers Missouri jobs and grid resiliency, February 2020
43 New Grain Belt Express transmission line to bring thousands of jobs to Kansas, September 2020
44 Community Benefits, August 2022

Ratepayers

The average ratepayer's two largest concerns are affordable and reliable electricity. The benefit of an interconnected grid during an extreme weather event is invaluable, especially in situations involving public health and safety. HVDC's economic contributions during extreme weather events cannot be understated; people should not have to choose between having unaffordable electric bills or putting their health in danger. During blue-sky conditions, ratepayers will see the tangible economic benefits of HVDC transmission in their monthly electric bills, in some instances decreasing consumer electric bills by 33%,[45] These savings are achieved by unlocking diverse, clean energy sources at unprecedented economies of scale. HVDC's reliability benefits are demonstrated by its interregional connectivity, black start capabilities, and engineering advantages

Electric Cooperatives, Public Power, and Public Utility Commissions

The role of energy regulators will evolve as the boundaries between private infrastructure and DoD energy assurance continue to meld. Central to this discussion is an understanding of how best to evaluate the relative benefits of proposed transmission projects in light of their ability to address the growing needs of energy resilience. Evaluating these benefits includes a recognition of the technical advantages of HVDC transmission to improve the efficiency of transporting more electricity—over longer distances—using fewer lines. Regulators will see first-hand impacts of an alleviated backlog of proposed transmission projects, reduced number of sites needed to achieve state climate goals, and increased reliability while having lower costs for their consumers.

Business Community

The business community has an opportunity to strengthen the U.S. economy, create a more secure supply chain, and enhance the transition to clean energy. Employers are incentivized to establish operations to meet growing demand, especially in the manufacturing sector. Most of the world's HVDC component manufacturers are based in Europe, as European Union member countries have been committed to clean energy deployment and HVDC buildout. This trend is beginning to shift as HVDC manufacturers continue to open large-scale operations in China. Similar to China's rise in solar panel production, their HVDC manufactures are able to undercut the worldwide market through government partnerships, and have already deployed products to over 60 countries in the world.[46] DOE issued a Prohibition Order that banned the import of critical electric infrastructure from adversarial nations, calling out the People's Republic of China specifically.[47] Although the Order was later rescinded, similar actions would limit the U.S.' ability to procure electric grid infrastructure.

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45 Consumer, Employment, and Environmental Benefits of Electricity Transmission Expansion in the Eastern U.S., October 2020

46 A Review of HVDC in China, April 2012

47 Notice of Request for Information (RFI) on Ensuring the Continued Security of the United States Critical Electric Infrastructure, April 2021

China has been able to create jobs and build their local economy through investment in a clean energy economy and HVDC buildout. America now has the opportunity to follow suit, and companies are beginning to notice. Siemens Gamesa announced they will be opening the U.S.' first offshore wind turbine factory in Virginia. This new facility will create approximately 260 jobs and provide a $200 million boost to the economy. Dominion Energy's CEO praised the impacts of this new facility saying it "is a major win for the region, and "[i]t is great to see well-paying, clean energy jobs are on the horizon as an offshore wind supply chain develops here in Virginia." As the clean energy transition progresses, businesses are ready and eager to invest in American operations and HVDC lines are vital to make this vision a reality.

SECTION 6. THE CALL TO ACTION HVDC

Today's electric grid does not have the capability to mitigate the national security risks facing the U.S. Transmission investment is essential in facilitating meaningful growth in clean energy deployment across the country. Rather than a compartmentalized approach using only AC transmission, the deliberate addition of HVDC lines binds together the regions of the U.S. grid in a way that unlocks the resilience needed to support energy customers at every level. Addressing domestic risk to communities and DoD installations across the country requires grid functionality that reflects the complexity of the manmade and climate-driven threats we face. Foreign energy dependence cannot be addressed until the full potential of domestic clean energy resources are harnessed and delivered coast-to coast.

The complex nature of national security risk requires a comprehensive approach to energy resilience solutions. The increased level of control provided by HVDC enables grid operators to accept large quantities of solar and wind, as the resources can be integrated into power flows in a manner similar to traditional generation technologies. If the electric grid is a beating heart supplying energy to the U.S., HVDC projects like the Grain Belt Express provide three vital functions in one:

- **A main artery:** Supplying new energy resources and connecting geographic regions in ways that were not previously possible. HVDC transmission systems allow for generation sources to be hundreds of miles away from the loads they serve, enabling the clean energy resources available in the Southwest and the Great Plains to be directed to any region across the country.

- **A pacemaker:** Smoothing out frequency irregularities that would otherwise disrupt power flow. The increased level of control provided by HVDC enables grid operators to accept large quantities of solar and wind since the resources can be integrated like traditional generation technologies.

- **An emergency AED:** Like a defibrillator restarting a heart, HVDC can restart the system during a major disruption capable of compromising national security. This includes unique resilience benefits related to HVDC's controllability, stability, and access to a diverse energy supply.

DoD's recent efforts to set installation energy resilience requirements brings clarity to the process of understanding what the electric grid needs to provide in order to address domestic and international security risks. DoD's extensive and diverse energy needs offer a roadmap of design and performance requirements to drive the development and use of the technical capabilities offered by investment in HVDC transmission. An essential step in the process is for the Federal Government to take deliberate and unified action, prioritizing energy resilience as an essential element of the future grid. FERC, DOE, and DoD should collaborate to ensure the requirements of national security are integrated into grid planning and policies. A more secure, clean and resilient grid is not an option, but rather a national imperative that must be met.

APPENDIX A. ABOUT INVENERGY AND CONVERGE STRATEGIES

About Invenergy Transmission

Invenergy Transmission's growing portfolio of projects includes Grain Belt Express, Clean Path NY, New Mexico North Path, and other greenfield development projects. Together, these projects will unlock enough 100% domestic, clean electricity for over 5 million US homes while supporting American jobs, local economies, and national security. Totaling over $15 billion of combined infrastructure investment and over 1,700 linear miles, Invenergy's portfolio of transmission projects are superhighways to the renewable energy transition. Learn about Invenergy Transmission at Invenergy.com.

About Converge Strategies, LLC

Converge Strategies, LLC (CSL) is a consulting company focused on the intersection of clean energy, resilience, and national security. CSL works with civilian and military partners to develop new approaches to energy resilience policy and planning in the face of rapidly evolving threats, vulnerable infrastructure, and determined adversaries.

To learn more about CSL, visit: www.convergestrategies.com.

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Meredith Pringle is a Director at Converge Strategies, LLC and specializes in energy resilience strategies for critical facilities. Meredith leads energy resilience workshops across the Department of Defense (DoD) to identify energy resilience project opportunities through collaboration with mission operators, service program offices, and external stakeholders. Meredith has developed resilience assessment frameworks for military and civilian partners across the country for the DoD, civilian airports, and cities with critical infrastructure. Meredith is a certified Project Management Professional (PMP) and trained facilitator focusing on multi-stakeholder energy resilience workshops.

Alex Pina is a Director at Converge Strategies, LLC and specializes in technical aspects of energy resilience. Alex focuses on community resilience, energy security, and distributed energy planning. Alex has extensive experience with conducting black start exercises and tabletop exercises that identify gaps between mission requirements and infrastructure capabilities. At Converge Strategies, Alex supports project planning and developing with partners such as SAF/IE, NAVFAC, and DASA/EIE. Before joining Converge Strategies, Alex worked at MIT Lincoln Laboratory as a technical staff member for 5 years. Alex also served as the founder and CEO of Avalanche Energy, where he developed a solar hot water system for residential applications. Alex holds a S.B. in Aerospace Engineering and a S.M. in Engineering and Management from the Massachusetts Institute of Technology.

Matt Aronoff is a Senior Associate at Converge Strategies, LLC. Matt builds public-private partnerships to accelerate a clean, resilient, and secure energy future. Prior to joining Converge, Matt served as a program analyst for the U.S. Department of Energy. In this role, he led engagement with developers, provided research and analysis for proposed transmission lines, managed the Electricity Advisory Committee, and supported the electricity sector's COVID-19 response. He also has previous experience with political campaigns and on Capitol Hill. Matt received his BS in Natural Resources and Environmental Sciences from the University of Illinois Urbana-Champaign.