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## Expanding the US Power Grid: AC vs. HVDC Transmission Lines

## White Paper

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# Executive Summary

The United States power grid faces a growing challenge: integrating renewable energy sources and delivering power across vast distances necessitates significantly upgrading the existing transmission infrastructure. This white paper explores the advantages and disadvantages of two primary technologies vying for dominance in this expansion: high-voltage alternating current (HVAC) and high-voltage direct current (HVDC) transmission lines. By understanding the strengths and weaknesses of each approach, informed decisions can be made to create a more efficient, reliable, and sustainable US power grid.

# Introduction

The sprawling network of the US power grid, built over decades, is at a critical juncture. The urgent need to transition towards renewable energy sources and address the challenges of long-distance power transmission necessitates a significant overhaul of our transmission infrastructure. This white paper presents a comprehensive analysis of high-voltage alternating current (HVAC) and high-voltage direct current (HVDC) transmission lines, offering insights into a strategic approach to grid modernization.

# The Legacy of AC Transmission

HVAC transmission has formed the backbone of the US power grid for over a century. Its advantages include:

**Extensive Existing Infrastructure:** A vast, pre-existing network of AC transmission lines is already in place.

**Ease of Voltage Transformation:** Relatively simple equipment facilitates voltage transformation for efficient power distribution.

**Lower Converter Station Costs:** AC converter stations' upfront costs are generally lower than HVDC stations.

These factors make HVAC a viable option for power distribution over shorter distances and upgrading existing AC grids.

# Limitations of AC Transmission

However, AC systems face several inherent limitations:

**Power Loss:** Energy is lost as heat due to resistance along transmission lines, known as power loss. This loss increases significantly over long distances, compromising overall efficiency.

**Reactive Power Management:** AC systems require reactive power management, which—though necessary for voltage stability—does not contribute to actual power delivery. This introduces operational complexity and additional infrastructure costs.

**Limited Control over Power Flow:** Precise control over the direction and magnitude of power flow in AC systems is limited. This complicates the integration of intermittent power sources, such as those based on wind and solar, and grid congestion management.

# The Potential of HVDC Transmission

HVDC transmission technology offers a compelling alternative, particularly for long-distance power transfer. Here are the key advantages of HVDC:

**Reduced Power Loss:** DC experiences significantly less resistance along transmission lines than AC, dramatically reducing power loss over long distances.

**Increased Transmission Capacity:** HVDC lines can carry more power than similarly sized AC lines, owing to the absence of reactive power issues. This translates to increased efficiency and the ability to transmit more power without additional infrastructure.

**Enhanced Control Capabilities:** A key strength of HVDC systems lies in their advanced control capabilities. They precisely regulate power flow direction and magnitude, allowing for smooth integration of renewable power sources and real-time grid stability management.

# Challenges and Considerations in HVDC Adoption

Despite the evident benefits of HVDC transmission, it's essential to consider particular challenges:

**Higher Converter Station Costs:** HVDC converter stations are significantly more expensive than their AC counterparts, presenting a significant cost consideration.

**Grid Integration Complexity:** Integrating HVDC systems into predominantly AC grids can be complex, requiring additional equipment and expertise for conversion between AC and DC systems.

**Cost-Effectiveness for Short Distances:** The cost-effectiveness of HVDC drops for shorter transmission distances or integration within established AC power distribution systems.

# A Hybrid Approach: The Best of Both Worlds

A strategic approach to grid modernization likely hinges on a well-considered combination of AC and HVDC technologies. AC remains a suitable choice for:

**Short-Distance Transmission:** AC lines can efficiently manage power distribution over shorter distances.

**Local Power Distribution:** Existing AC infrastructure is well-suited for local power distribution within established grids.

**Upgrades within Established AC Networks:** Upgrades to existing AC grids can be cost-effectively implemented using AC technology.



# A Hybrid Approach: The Best of Both Worlds

Conversely, HVDC excels in the following scenarios:

**Integrating Remote Renewables:** HVDC provides a highly efficient means to transport energy generated by remote wind farms, large-scale solar installations, or geographically isolated geothermal plants over vast distances.

**Grid Interconnections and Stability:** HVDC lines can strengthen connections between regional grids. They offer enhanced control over power flow, improving overall reliability, resilience, and grid stability.

**Underwater Transmission:** HVDC technology is the preferred choice for efficient power transmission over long distances underwater, a requirement in connecting offshore wind farms to the mainland grid.

# Recommendations

Based on the analysis presented, the following recommendations are made for grid modernization efforts:

## **Invest in Long-Distance HVDC Links:**

Prioritize investment in HVDC transmission lines for transporting renewable energy from remote areas to population centers, minimizing transmission losses.

## **Strengthen Interconnections with HVDC:**

Use HVDC lines to enhance the interconnection of regional grids for improved reliability, facilitating power-sharing during emergencies or peak demand.

## **Leverage HVDC for Offshore Wind:**

Employ HVDC technology to connect offshore wind farms to the mainland over long undersea distances, maximizing efficiency.

# Recommendations

**Utilize AC for Short-Haul and Local Distribution:** Continue to rely on AC systems for short-distance transmission, grid upgrades within established networks, and local power distribution.

**Develop a Hybrid Grid Architecture:** Design a hybrid power grid architecture that leverages the strengths of both AC and HVDC technologies for optimal power transmission.

The future of the US power grid hinges on the intelligent integration of transmission technologies. By adopting a nuanced approach that recognizes the specific advantages of AC and HVDC, we can build a more sustainable, resilient, and efficient power grid. The investments made today will shape the energy landscape for decades, influencing the accessibility of renewable power and ensuring a reliable energy supply for future generations.

# Conclusion

Modernizing the US power grid demands a sophisticated approach that balances technological advancements with economic realities. By recognizing AC and HVDC technologies' specific advantages and limitations, we can make informed investment decisions. A strategic mix, where each technology is deployed in areas of its greatest strength, will pave the way for a future power grid that is efficient, reliable, sustainable, and capable of meeting tomorrow's energy needs.



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