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Renewing the Grid: High-Voltage Direct Current Transmission for Greater Renewable Energy Development

Key Findings

- Because wind and solar potential is often highest in rural areas, long-distance transmission lines are often needed to transmit electricity from remote generation resources to load centers.
- By connecting geographically dispersed resources through long-distance transmission lines, the intermittency of renewable generation can be somewhat mitigated.
- Over long distances, High-Voltage Direct Current (HVDC) transmission lines have the advantage of minimizing the reliability impacts of connecting remote generation to the bulk electric power system, minimizing energy loss and lower construction cost per mile.

What has changed?

As of May 2019, twelve (12) states have adopted clean energy standards, and many utilities are adopting voluntary targets that range from an 80 percent reduction in greenhouse gas (GHG) emissions by the mid-century to complete carbon neutrality by 2035.[1] Pursued independently, these goals may require substantial investments in energy storage. However, if these goals can be scaled to a national effort, there can be cost and efficiency advantages in developing a high-voltage direct current (HVDC) transmission network to facilitate the connection of remote generation resources to the grid.

When the first electric power systems were developed in the 1880s, there was no way to transform DC power to higher voltages for transmission, which limited the distance between generation and load to approximately half a mile. Because of this, the vast majority of transmission lines are high-voltage alternating current (HVAC). However, with the invention of mercury arc valves and later thyristors, these challenges were overcome, and DC emerged as a viable choice for long-distance and submarine transmission, offering minimized energy loss compared to AC, better controllability of power flow, and, past certain distances, lower costs.[2]

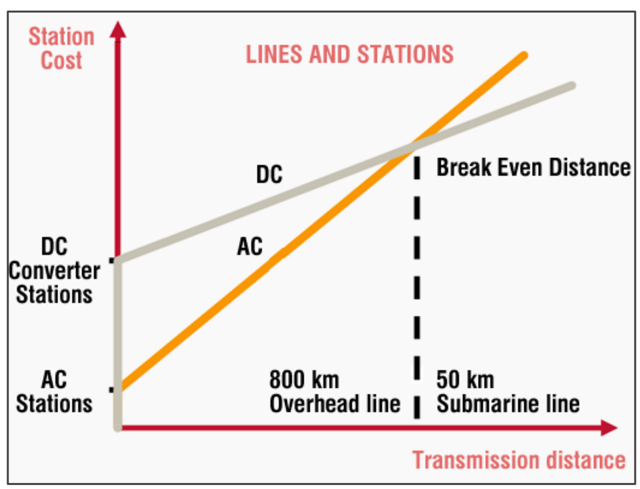

Figure 1: AC vs DC Transmission Prices by Distance. (Electrical Engineering Portal)

[1] Clean Air Task Force. "Fact Sheet: State and Utility Climate Change Targets Shift to Carbon Reductions, Technology Diversity." May 5, 2019. Available at: https://www.catf.us/wp-content/uploads/2019/05/State-and-Utility-Climate-Change-Targets.pdf.
[2] Michael Hartnack. "HVDC: The Future of Long-Distance and Renewables Transmission." *Navigant Research.* Jan. 2018. Available at: https://www.navigantresearch.com/news-and-views/hvdc-the-future-of-long-distance-and-renewables-transmission.

How Does HVDC Help?

One of the primary challenges to 100 percent renewable energy is the inherent variability of renewable resources in response to the time of day and changes in the weather. For instance, while utilities can easily anticipate that solar generation will stop at night, it is often harder to predict variations in generation in the middle of the day. However, these fluctuations can be mitigated to some extent when the resources are located across a larger geographic area.[3]

As cloudy skies and calm winds reduce generation in one area, other areas may be experiencing higher generation output from wind and solar resources. The net result of this is that areas with reduced renewable output turn to generation from fossil fuels to make up the difference, as areas with higher renewable generation might have curtail output to prevent grid instability. One solution to this situation would be to transmit excess energy to areas where resources are underproducing, but this is limited by capacity constraints and a lack of long-distance lines in the current transmission network.

According to researchers from the National Oceanic and Atmospheric Administration (NOAA) and the University of Colorado (CU), building HVDC lines across the transmission network in key regions could enable up to a 78 percent reduction in emissions relative to 1990 levels.[4] (See Figure 2.) These reductions would stem from more efficient use of existing renewable resources and from increased investment in renewable generation due to the potential for additional revenues from exporting generation to other areas.

In the NOAA/CU reference case, which is based on 2015 renewable energy and natural gas prices, emissions would be reduced by 61 percent relative to 1990 levels, and consumers would save an estimated $47.2 billion per year, representing an approximately 3:1 rate of return on the HVDC transmission investment. These savings come from lower overall variable generation costs,[5] minimization of transmission loss, and reduced use of expensive peaking resources that backstop renewables.

While remote renewable energy resources will likely be the primary driver of HVDC development, it should be noted that the benefits of HVDC are not limited to balancing renewable energy output. Rather, HVDC exists as a promising technology for connecting any remote resource to the larger network, whether it be a coal plant (e.g. Great River Energy's CU line between North Dakota and Minnesota), a hydroelectric facility (e.g. the Pacific DC Intertie), or an offshore wind turbine (via a submarine cable).

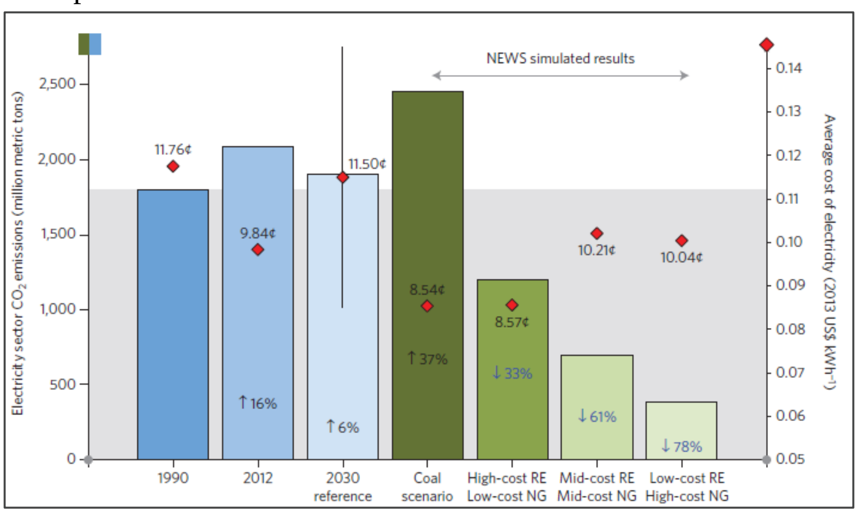

Figure 2: Reductions in Emissions with HVDC. (NOAA and University of Colorado Boulder)

[3] Carnegie Mellon University. "Managing Variable Energy Resources to Increase Renewable Electricity's Contribution to the Grid." Available at: https://www.cmu.edu/epp/policy-briefs/briefs/Managing-variable-energy-resources.pdf.
[4] Alexander E. MacDonald et al. "Future Cost-Competitive Electricity Systems and Their Impact on US CO_2 Emissions." January 25, 2016. Available at: http://denning.atmos.colostate.edu/readings/Solutions/Macdonald.HVDC.pdf.
[5] Lower energy prices are relative to the 2030 reference case as projected in the Energy Information Administration's 2015 Annual Energy Outlook (AEO2015).

However, it should also be noted that HVDC is most appropriate for direct or "point to point" transmission, where a generation from the region at the initial point of the transmission line is transmitted directly to the terminal point of the line, without off-shooting interconnections to other regions. Thus, HVDC is more appropriate for large generation sources (e.g. wind farms or thermal plants) rather than smaller, geographically dispersed resources such as solar farms.

What is the Status of HVDC Now?

Despite the potential advantages of HVDC, commercial acceptance has been tepid at best, with only 20 HVDC lines in service in the U.S. today.[6] Even as renewable penetration rates are projected to increase, only 1,300 circuit miles of HVDC are currently planned or under construction within the NERC regions of the U.S. and Canada through 2021.[7] One reason for this is increased local opposition to large infrastructure projects, as evidenced by the indefinite postponement of the Plains & Eastern Clean Line, which encountered significant opposition in Arkansas.[8] Another key obstacle is a complicated regulatory environment, which is responsible for the delays in the Grain Belt Express and Rock Island Clean Lines. [9]

For an interstate transmission project to proceed, developers must receive approval from local, state, and federal authorities. If a single approval is denied, the entire project must be reimagined or abandoned altogether. At the same time, because interstate projects generally benefit multiple regions, everybody involved must come to an agreement about how to share the costs. Unfortunately, these negotiations have been mostly unsuccessful to date, and interregional transmission has largely failed to materialize. However, as FERC considers re-evaluating Order 1000 this year,[10] these issues may be revisited to the benefit of HVDC deployment.

Beyond stakeholder opposition and the complicated regulatory environment, the primary challenge in transitioning to an HVDC transmission network has been the cost associated with converting DC to AC at the end of the line. However, for longer lines these costs are offset by savings from reduced energy losses and lower construction costs (due to needing fewer conductors, less line insulation, and smaller towers). See Figure 3.

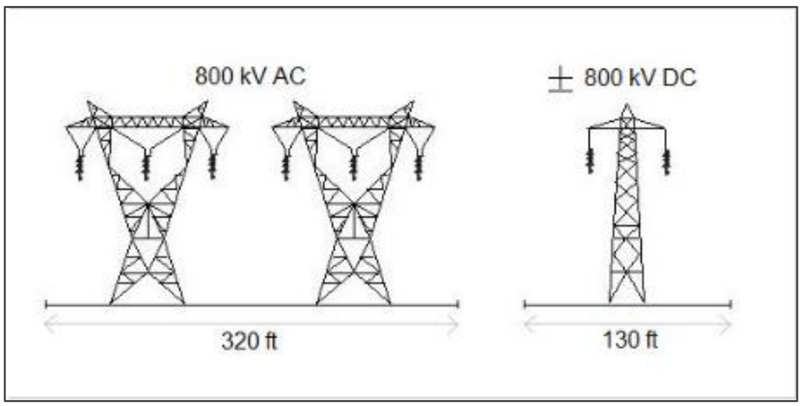

Figure 3: Comparison of AC and DC Transmission Towers.
(All About Circuits)

[6] Mordor Intelligence. "United States High-Voltage Direct Current (HVDC) Transmission Systems Market Outlook to 2020." Available at: https://www.mordorintelligence.com/industry-reports/united-states-high-voltage-direct-current-hvdc-transmission-systems-market-industry.
[7] NERC. "Electricity Supply and Demand (2018)." Available at: https://www.nerc.com/pa/RAPA/ESD/Pages/default.aspx
[8] Tom Kleckner. "Arkansas Landowners Seek to Stop Plains & Eastern Clean Line Project." *RTO Insider*. Aug. 2016. Available at: https://rtoinsider.com/arkansas-plains-eastern-clean-line-30539.
[9] Clean Line Energy Partners. "Grain Belt Express – Regulatory Approvals." Available at: https://www.grainbeltexpresscleanline.com/site/page/regulatory_approvals.
[10] Herman Trabish. "With New Transmission Urgently Needed, FERC Chair hints at a New Order 1000 Proceeding." *Utility Dive*. May 31, 2019. Available at: https://www.utilitydive.com/news/with-new-transmission-urgently-needed-ferc-chair-hints-at-a-new-order-1000/555586/.

Due to these challenges, the U.S. trails other countries in terms of both voltage and capacity levels for DC transmission. While voltage levels top out at 600 kV in the U.S., China has commissioned 800 and 1,100 kV ultra-high voltage (UHVDC) lines that stretch up to 1,230 circuit miles,[11] and similar UHVDC projects have been or are being undertaken in India, Brazil, South Africa, the Middle East, Southeast Asia, and Europe.[12]

However, it should be noted that new lines are not the only pathway to a nationwide HVDC transmission network. A common practice in Europe has been to convert existing overhead AC lines to DC, which allows the power transmission rating to be more than tripled at a third of the cost of a new line.[13] As building new lines becomes difficult, this option will likely become an attractive alternative for transmission developers.

What is the impact on cooperatives?

At the end of 2018, cooperatives had nearly 8.5 GW of wind and solar capacity in their portfolios, primarily through long-term power purchase agreements, with more than 3 GW planned through 2022. As declining prices, state and federal policy, and increasing interest from member-consumers continue to drive renewable development, mitigating the intermittency of these resources will become increasingly important, especially as older fossil-fuel resources retire. HVDC transmission can help to achieve that goal.

What do cooperatives need to know or do about it?

In areas where renewable generation is regularly curtailed, long-distance transmission could help address low or negative market prices, while simultaneously bringing in revenues from other regions and helping to reduce generation curtailments. HVDC could also be used to bring renewable energy from high-resource areas into areas with lower resources, potentially at a lower cost than deploying renewable resources locally. The resulting interregional exchange of renewable energy would not only contribute to state and regional climate goals but would also add an element of resilience by creating high-capacity links to neighboring regions.

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[11] Sonal Patel. "Readying for New HVDC Line, U.S. Lags Behind Rest of World." January 1, 2017. Available at: https://www.powermag.com/readying-new-hvdc-line-u-s-lags-behind-rest-world/.
[12] Michael Ames. "Global HVDC Transmission System Market-Global Demand Analysis & Opportunity Outlook 2024. *Energy News Today*. June 4, 2019. Available at: https://energynewstoday24.com/2019/06/04/global-hvdc-transmission-system-market/.
[13] Michael Hausler. "Converting AC Power Lines to DC for Higher Transmission Ratings." *ABB.* Available at: https://library.e.abb.com/public/139412d24d16673fc1257b1a005b4ce8/04-11%20ENG%209703.pdf.