WHITE PAPER / **TAPPING INTO THE POWER OF HVDC**

HOW UTILITIES CAN CONVERT ASSETS AND INCREASE CAPACITY

BY Marianne Goldsborough

Upgrading electrical transmission systems to high-voltage direct current (HVDC) can increase capacity by thousands of megawatts with relatively few complications and no need for additional right-of-way. Using a stage gate review process, utilities can determine the right way toward more efficient energy transmission.

Using existing transmission line infrastructure and assets, utilities can convert existing alternating current (AC) systems to high-voltage direct current (HVDC) and achieve greatly increased capacity of electric transmission systems with minimal line loss, more efficient use of existing rights-of-way and assets, and minimal environmental or regulatory impact. HVDC offers considerable opportunity, with benefits like power flow control and stability controls, but a thorough evaluation of the right conversion path is needed to attain project success.

STATE OF THE NATION

In the late 1880s, the War of the Currents broiled between inventors Thomas Edison and Nikola Tesla. Direct current (DC), developed by Edison, runs in a single direction but was not believed to be easily altered to lower or higher voltages. Tesla's AC addressed this problem by reversing the current flow every 60 seconds and converting voltages using a transformer.

By the end of the 1890s, AC was adopted as the preferred means of electric power generation, and transmission grids began to spread across the country. Today, there are more than 700,000 circuit miles of lines in the U.S., most of which operate using AC.

Although electricity is still mainly transmitted by AC, changes in many technologies, new energy production sources and the need for efficient electricity distribution have increased demand for steady and unidirectional energy flow. HVDC is the bulk transmission workhorse to deliver what's needed.

WHAT IS HVDC?

A proven technology, HVDC is used to transmit electricity over long distances, either by overhead transmission lines or underground cables. Something like an electrical superhighway, an HVDC system can efficiently transfer large amounts of electrical power with minimal energy loss.

With a rated power of more than 100 MW, and many in the 1,000- to 3,000-MW range, transmitting electricity using HVDC requires two converter stations.

LINE-COMMUTATED CONVERTERS (LCC)

The more traditional systems used in HVDC systems, LCC offers much more power and the following characteristics:

- Multiterminal applications can be complicated.
- Excellent for clearing DC line faults quickly with fast, automatic restart capabilities.
- Current ratings of thyristors are much higher (6 kA), allowing for higher-capacity converter valves.
    - 3,000-MW bipole is no problem.
- No black start capability.
- Requires AC filtering.
- Consumes reactive power at converter stations.
- Larger footprint than VSC.

VOLTAGE-SOURCED CONVERTERS (VSC)

A newer and more compact technology, VSC has lower power capabilities and the following characteristics:

- Best for multiterminal applications.
- Challenges with clearing DC line faults (requires tripping of the entire system, full bridge converters or HVDC breakers).
- Current ratings of insulated-gate bipolar transistors (IGBTs) of approximately 3 kA limit converter valve capacity.
    - 3,000-MW bipole is at the upper limit of today's technology.
- Black start capabilities.
- Good for integrating renewables.
- Requires no AC filtering.
- Capable of providing independent reactive power control at converter stations.
- Smaller footprint than LCC.

HVDC CONVERTER TECHNOLOGIES

HVDC converter technologies are well established and include two categories: line-commutated converters (LCCs) and voltage-sourced converters (VSCs). With LCCs, electronic switches can only be turned on, whereas VSCs can be switched on and off. Both technologies offer advantages and disadvantages for utility applications.

HVDC SYSTEM COMPONENTS

The simplicity of HVDC systems streamlines conversion projects. An HVDC system consists of a converter station to convert AC to DC, transmission line, and a converter station to convert DC back to AC. The systems can be designed, configured and linked in different arrangements, with the most common being:

- **Bipolar system:** A converter for each terminal to create two independent DC circuits.
- **Monopolar system:** For moderate power transfers using two converters and one conductor.
- **Back-to-back station:** Two converters on the same site without a transmission line, usually used to tie between two different AC transmission systems.
- **Multiterminal system:** Two converters connected by a transmission line.

The beauty of converting systems to HVDC is the ability to change the tower head and use the exact footprints and rights-of-way of existing towers to upgrade the electrical system. While some structural steel may be needed for reinforcement, no additional permanent tower structures are required.

A substation upgrade and expansion for converters is also needed, and if it is determined a new substation is required, that represents a modest addition when compared to routing new transmission lines in the area.

HVDC, RENEWABLE ENERGY AND THE GRID

Large renewable energy resources are often located in rural areas, some distance from load centers. HVDC is well-suited for renewable energy transmission, given its better efficiency over long distances and minimal losses that allow more power to be delivered to the destination.

In 1970, the U.S. completed its first commercial HVDC project to deliver hydropower from the Bonneville Power Administration in the Pacific Northwest to Los Angeles Department of Water and Power territory in California. Stretching more than 800 miles, this HVDC system has been upgraded and now offers a capacity of 3,220 MW with plans for additional expansion.

The Energy Information Administration (EIA) classifies renewables into categories of generating sources:

- Dispatchable: Generators that respond to real-time instructions to increase or decrease output.
- Non-dispatchable: Generators dependent on the availability of naturally occurring resources, such as wind energy or solar.

It is noted that hydroelectric generators fall between these categories, given that they can respond to dispatch signals but have seasonal operating limits that can prevent dispatching.

In a recent report examining the role of HVDC lines for integrating renewables, the EIA notes several advantages of DC transmission over AC lines:

- More cost-effective over long distances
- Lower electricity losses
- Better equipped to handle longer periods of overload
- More suitable for underwater applications
- Capable of preventing cascading failures

While HVDC is well-suited to transmit renewable energy, the advantages it offers extend to the entire grid. Increasing the efficiency of transmission, no matter the energy source, creates a more robust and reliable grid.

Although AC systems have lower capital costs, operating costs increase over distance and at high voltages (i.e., losses). HVDC system conversions require the capital cost of converter stations but, due to reduced losses, they offer lower operating costs.

Private companies offer proprietary HVDC technologies and converters. Understanding what is needed for optimal efficiency and the right price is the only way utilities can develop an execution plan that will meet project goals and achieve operational improvements.

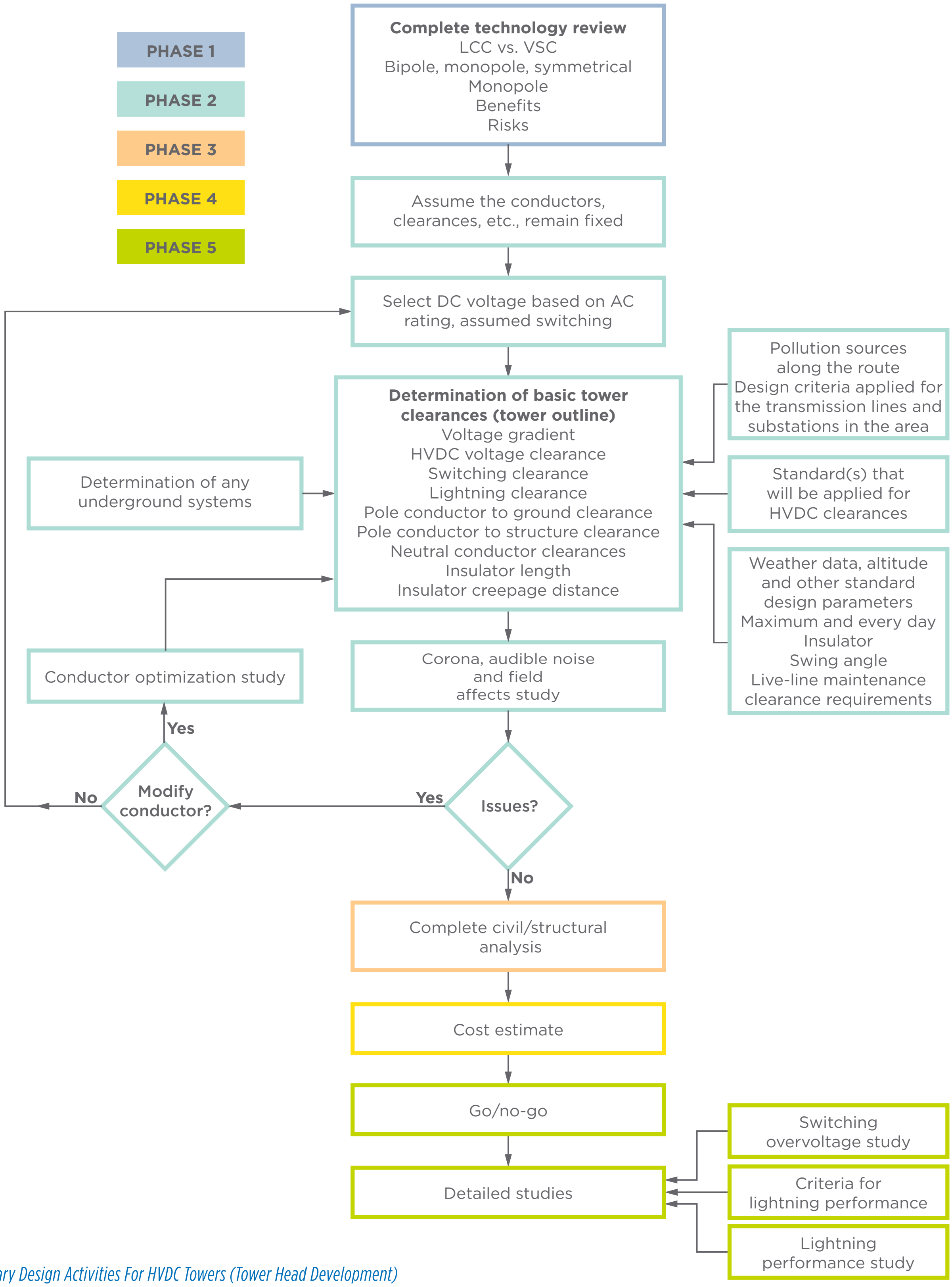
THE BENEFITS OF HVDC FOR UTILITIES

Whether for increased efficiency, planning for load growth or handling renewables coming online, utilities may be able to increase their AC system capacity by converting to a DC system with minimal line modifications for several advantages, including:

- **Shorten project time:** New power projects require considerable time to determine suitable rights-of-way (ROW), comply with the regulatory process, provide public consultation and secure approval. With no fundamental changes to infrastructure, HVDC upgrades enjoy a considerably shortened lead time for approval.
- **Minimize environmental impact:** Retrofitting existing towers, minimizing overhead lines, utilizing the same corridors and ROW, and deferring the need for new power stations minimizes the environmental impact and maximizes the power efficiency.

- **Extend the reach of renewable energy:** HVDC systems are optimal over long distances, whether overhead or underground. By tapping into or extending an HVDC system, renewable energy can be transmitted from remote locations to more congested, urban areas and other parts of the country for greater environmental benefit.
- **Push more power:** Regardless of the distance, HVDC lines deliver more power because the electricity needs fewer wires and can travel through the entire section of a conductor.
- **Achieve less loss:** HVDC lines produce no heat generation and only a static electromagnetic field, resulting in lower losses than AC systems of the same capacity.
- **Increase line capacity:** More electricity can be transmitted over the existing transmission lines. Utilities can maximize capital while maintaining structure and locations by modifying only the head of the transmission tower.

These benefits focus on converting existing AC systems to HVDC, but advantages can also be achieved during the execution of new power projects. With upfront planning, new electric transmission systems can be designed cost-effectively for future HVDC system upgrades and capacity to address projected load growth.



Preliminary Design Activities For HVDC Towers (Tower Head Development)

STAGED APPROACH TO GETTING STARTED

Upgrading an AC system to an HVDC power system is a big project. It is essential utilities break down the process and undertake methodical, objective consideration.

Using a stage gate process provides the opportunity for a complete evaluation of the possibilities for HVDC conversion, with identified points along the way to determine whether to proceed or stop.

Utilities should rely on a robust and comprehensive evaluation process to analyze the many interrelated components and determine the right approach for HVDC conversion projects:

- Technical feasibility analysis of towers and cable duct banks.
- Determine cable duct bank reuse options.
- Complete technology review, benefits and risks of LCC vs. VSC options and configuration options.
- DC line design based on switching surge factor.
- DC insulator recommendations.
- Tower head arrangement options.
- Environment effects analysis and earth magnetic field (EMF) values calculated.
- Lightning performance evaluation.
- Structure and clearance review for each proposed converter option.
- Evaluation of any structural overstress and necessary tower updates.
- Outage costs for conversion, which should factor into design and installation considerations.
- Compliance to applicable local codes and specifications.
- Budget options for transformers and engineering, material and construction of all conversion options.

By insisting on a disciplined process and making sure each review stage is analyzed and approved before proceeding, utilities can control costs and expectations for HVDC conversion projects.

CONCLUSION

For utilities in the U.S., upgrading existing AC systems to HVDC can improve power transmission, lower losses and increase efficiency, all with minimal environmental impact and without lengthy regulatory processes and reviews. New electric system projects can achieve similar benefits by designing HVDC capability from the outset for conversion in the future.

While HVDC conversion is often feasible and an attractive option for upgrading utility assets, it is key that systematic, staged review processes are in place to avoid cost surprises when only evaluating part of the project.

Through relatively small investment, utilities can achieve a comprehensive assessment of what HVDC conversion path is the best for improved redundancy and reliability with little upfront risk but potential for great long-term benefit.

BIOGRAPHY

MARIANNE GOLDSBOROUGH is a project manager for Burns & McDonnell, overseeing the design, engineering and construction of substation and transmission line projects. With more than 30 years of experience in the electrical utility sector, Marianne specializes in HVDC and HVAC conversions, substations, transmission and distribution lines, and underground AC systems. Marianne earned her Bachelor of Science in electrical engineering and an MBA from the University of Manitoba.

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