Interstate Electric Transmission: Enabler for Clean Energy

Michael Heyeck, PE, Senior Vice President, Transmission
Evan R. Wilcox, Transmission Planning Engineer
American Electric Power
April 2008

Executive Summary

A century ago, the electric industry was a patchwork of local utilities designed to generate local power for local customers with rudimentary requirements. As system requirements have changed and demand growth has escalated, the industry has not kept pace with that evolution, especially in light of an uncertain regulatory landscape. Today, many important national issues can be resolved through proper utilization of the electric industry and its infrastructure, with issues of energy security and climate change at the top of the list. Transmission is at the heart of many electric industry solutions to these national issues, as it possesses a unique ability to address reliability, generation access (including renewables and other environmentally-friendly technologies), and system efficiency.

It is important to do more than look at how energy is generated and consumed. Utilizing advanced transmission technologies can significantly increase the efficiency and reliability of the energy supply chain. By viewing the system as a whole - including diverse generation, efficient delivery of energy, and expanding smart grid initiatives - the maximum value of these efforts can be realized. We should be planning for an electric transmission system with the needs of the entire country in mind rather than the local fixes that compose the patchwork of today's transmission system.

The Evolving Role of Transmission

Following the development of alternating current (AC) electricity and its early applications, the grid has evolved through a series of higher voltages and subsequent increases in transmission distances. In basic terms, the higher the voltage, the more power that can be transmitted over a longer distance. This progression was driven largely by the economics of having multiple large generators connected over a wide area, and the desire to site generating plants near fuel/water sources and away from populated areas. As electricity use escalated and the size of generating plants increased, higher voltages were required to move power efficiently to load centers.

By the middle of the 20th Century, high voltages on AEP's system were 69-kilovolts (kV) to 138 kV. The company then moved to 345-kV, falling into a new class of "extra-high voltage" (EHV), and ultimately, in 1969, introducing 765-kV, the highest voltage used in the United States today. In other regions, utilities evolved from 115-kV and 230-kV to 500-kV. But even as EHV enabled the movement of bulk power over long distances, transmission's main purpose was to transport a company's own generation to its own customers within its own footprint. Interconnections between companies occurred largely to improve reliability and to enable mutual sharing of generation supply reserves, but later were increasingly utilized to trade power. With FERC Order

No. 888 in the mid-1990s, open access to transmission was granted to third parties, changing the system's dynamics. Transmission is no longer simply an intra-company transportation system. Instead, it has evolved into a facilitator of a newly-formed electricity marketplace with any number of individual participants across wide geographic regions. This evolution has consequences, both physical and economic, that challenges the way today's system operates and the way tomorrow's system must be planned.

There has been little investment in transmission infrastructure in recent years. Serious reliability concerns have emerged with the new electricity marketplace of today. This coupled with continued load growth and retirements of older power plants that were closer to load centers, has stressed the existing system beyond its designed capabilities.

Electric transmission now faces a new challenge with the rapid development of generation technologies designed to reduce the electric industry's climate change impacts. These technologies, including wind, solar, biomass, geothermal, clean coal, and nuclear, all need this same transmission system to enter the electricity marketplace and serve customers. Most of these new resources are often located far from the large population centers where the electricity that they generate is needed, much in the same way that transmission lines that were built decades ago to bring the energy generated by remotely located plants to customers in major cities. Unfortunately, these new resources are rarely clustered in the same locations and in many instances, such as with wind and solar, their locations are dictated by geo-physics. Our industry once again faces the challenge of facilitating the integration of new resources while at the same time addressing the continued need for reliability and meeting the demands of customers and the economy.

With this challenge, an opportunity exists to develop a new, technologically advanced transmission system that provides an enhanced level of reliability and efficiency while bringing new generating technologies into the U.S. energy mix. The difficulty: the vision of what this new system should look like differs from region to region and company to company. The design of a new, advanced transmission system is different depending on the problem being addressed. Providing access to wind generation, addressing reliability concerns, or addressing load growth may individually require different transmission solutions. Prudent transmission planning must weigh all the new demands of the system and should be designed to supersede the mindset of local or sub-regional planning.

Where we are today is not unlike where President Eisenhower was in the 1950s. The U.S. highway system was *not* a national system, but was a patchwork quilt and hardly capable of supporting a growing economy or the defense of our homeland. He could have supported "just in time" development or "incrementalization" of the U.S. highway system. Instead in June 1956, he signed into law a plan for a national interstate highway system that would serve the nation as a whole. Imagine our economy and national security today without this system. This system acted as an overlay to the existing lower volume roads, some of which were retired after its integration, and some of which were enhanced and conscripted into higher-level duties when the revitalized modern highway system was fully operational.

The interstate highway analogy can illustrate how transmission is inefficiently planned today to connect generation resources. Using this parallel, let's suppose Wal-Mart wants to site a store. They would file for access to the road system to accommodate the increased traffic brought on first by the construction project and then the shoppers. The studies show that $20 million in improvements are necessary. Then Target plans a store at an adjacent location and asks for road access. This study reveals a new interchange is needed for $200 million. The uncoordinated projects result in improvements that are neither as cost-effective as they might otherwise be, or as efficient in transporting vehicles as they would have been had they been planned together.

Obviously, this was not how the interstate highway system was built. Instead, it was built anticipating a 30-year growth horizon. Conversely, transmission is planned today with a "just in time," "incrementalization" approach that will not enable full development and deployment of the generation resources the U.S. economy deserves. The transmission planning horizon must recognize longer term needs in order to create a system that will support future development and be less expensive ultimately. Otherwise, we are at risk of unnecessarily restricting the development of new generation resources and jeopardizing future system adequacy and reliability.

Advanced Transmission Technology We Can Build Today: 765-kV AC Transmission

We need a national vision for interstate electric transmission similar to the vision President Eisenhower had when he created the national interstate highway system. A national planning concept has not been used for electric transmission because meeting larger, national needs were not the intent of the original transmission lines. Now, we have evolved from local generation resources serving local demand, to larger, more remote central stations serving cities, to today's system that enables regional resources to serve regional load. A new, high-volume EHV transmission system integrated as an overlay is needed to draw together our existing "patchwork" system and support national priorities.

The American Wind Energy Association (AWEA) proposes that the U.S. has 1.1 million giga-watt-hours annually of untapped wind potential, with the top five states for that potential being North and South Dakota, Texas, Kansas and Montana. Most of the U.S. population lives within 100 miles of our nation's coastlines with very little transmission capacity in between. This national disconnect between wind generation location and population location creates the nexus for the development of an interstate electric transmission system that can support wind generation development where the best resources are located and transport the electricity to where it is needed, whether California, New York, or points in between.

To be as efficient as possible both electrically and with land use, we propose EHV 765-kV transmission as the platform for developing an interstate electric transmission system across the U.S. Other countries in the world are considering "ultra-high voltage" (UHV) transmission at voltage levels of 1000-kV, but we believe the U.S. grid can be built efficiently with 765-kV transmission.

AC vs. DC

An EHV AC system should be the model for interstate transmission to ensure maximum connectivity and electricity deliverability on a nationwide basis. Today's grid is by and large an AC system, with direct current (DC) utilized as a complement to the AC system in special circumstances. 765-kV AC is the highest transmission voltage in the U.S. today, but is largely an underutilized technology outside of AEP's footprint. The use of 765-kV AC technology could create a new high-capacity bulk transmission grid overlaying the existing lower voltage system. Both systems could be easily integrated as a network through "on-ramps" and "off-ramps" where required. This type of integrated 765-kV AC grid, with ample capacity for future growth, would provide a solid foundation for reliable electricity service and provide ease of access to all generators and distributors of electricity. Furthermore, this type of overlay network would free up capacity on lower voltage systems such as 500-kV, 345-kV, and 230-kV. This is particularly important as this additional capacity allows operational, maintenance, and replacement flexibility, as well as the ability to connect new generation resources onto the existing system.

High-Voltage Direct Current (HVDC) can also efficiently carry bulk power over long distances. Typically, HVDC has around 30% lower per-mile line construction costs than 765-kV AC, but the power transfer is only economical on a long-distance point-to-point basis (generally over hundreds of miles point-to-point without intermediate interconnections).[1] Depending on the level of capacity required and the corresponding magnitude of AC/DC station conversion requirements, the cost ratio can be as high as three to four times the cost of a comparable AC station, and station losses can be higher. In spite of this, HVDC is better suited in special circumstances. For example, since there are less physical limitations for HVDC cables as compared to AC, HVDC is often the right choice for large-scale underground and undersea applications. In addition, HVDC is highly controllable and has been used as a means to manage power flows on weak systems.

In the case of large-scale renewable integration, generation in one particular location could essentially be connected to one load center through an HVDC line. To fully develop these resources, however, multiple individual lines in multiple directions would be required, with expensive converter stations for each line. While this would electrically bring an individual generator closer to a particular load center, there would be little interconnection ability and little benefit to the existing transmission system in between. Over these distances, it is likely that intermediate connections would be warranted. Renewable generation resources often cover wide geographic areas, and the cost to create multiple connections to multiple HVDC lines would be substantially higher. In addition, DC converter stations tend to be much more complex than standard AC stations. On-going needs such as maintenance and replacements are much more specialized and thus require a higher level of skill and higher cost than typical AC facilities. All of these factors need to be considered when considering large, long-standing projects.

An EHV AC network would allow for less complicated future connections of resources and integration into the underlying system. A system based on HVDC lines would lack the benefits of generation resource sharing, geographic diversification, and the ability to easily and

---

[1] Bahrman, Michael P and Brian K. Johnson. “The ABCs of HVDC Transmission Technologies.” IEEE Power & Energy Magazine 5.2 Mar/Apr. 2007: ABB Power Technologies. Apr. 2008 <http://www.abb.com/hvdc>.

economically connect future generators along the way. From the standpoint of public sentiment, siting challenges can be mitigated by flexibility that will allow one line to serve multiple purposes. Because the general public, as a rule, tends to oppose increased development of power lines near private property, building lines capable of multi-tasking makes sense. In general, HVDC lines are complementary to, but not a replacement for, a robust AC system.

Capacity and Environmental Considerations

If new transmission lines are not built for long-term needs, some of which are uncertain, additional lines on new right-of-way will be required as growth occurs and new generation resources develop. Due to environmental concerns and increasing landowner opposition issues, siting and building new transmission lines have become a considerable challenge. It is important to properly design transmission lines for maximum utilization of right-of-way initially to avoid the need for additional lines in the future.

In simple terms, higher amounts of power can be transmitted if transmission voltages are higher. Approximately three single-circuit 500-kV lines or six single-circuit 345-kV lines would be required to carry an equivalent amount of power as one 765-kV line.[2] This relative comparison of higher voltage, higher capacity holds true for HVDC lines as well.

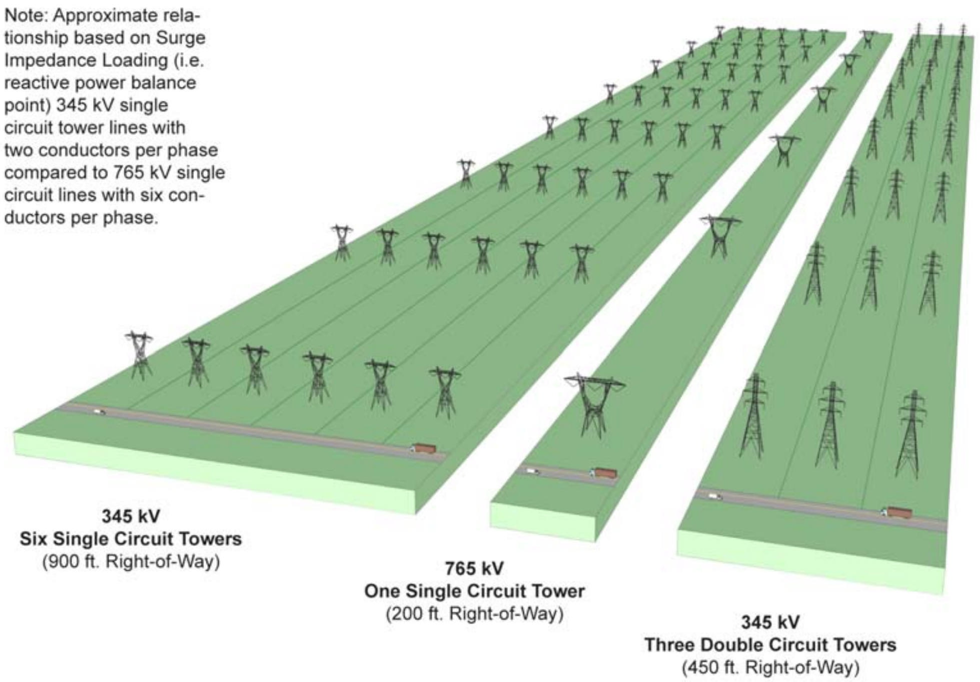

Exhibit 1: Right-of-way comparison for equivalent capacity of 765-kV and 345-kV lines.

---

[2] "Practical Concepts in Capability and Performance of Transmission Lines," H.P. St. Clair, AIEE Transactions on Power Apparatus and Systems, Vol. 72, Part III, December 1953.

A 765-kV interstate network overlaying the lower-voltage system makes the best use of land resources as well as the existing infrastructure. This is accomplished by providing a long distance transportation channel while continuing to employ the lower-voltage system for more localized needs. As electricity follows the path of least resistance (higher voltage equates to lower impedance for power flows), this overlay would bear longer distance power transfers now flowing on lower-voltage lines, but with the added flexibility of integrating at multiple points along the path. As a result, capacity on the existing system is free to allow for the connection of new resources and additional operating margins. Building transmission lines at lower voltages would require more lines to accomplish the same objective. AEP uses a minimum right-of-way width of 200 feet for its 765-kV construction. The standard right-of-way width for a 500-kV line also is 200 feet. For 345-kV construction, 150 feet is typically used. For equivalent power carrying capability, lower voltages require more lines and as a result more land for right-of-way. As shown in Exhibit 1, even double-circuit 345-kV towers (average tower height is 170 feet) would require more right-of-way than 765-kV. In terms of capacity per unit of right-of-way required, 765-kV (average tower height is 130 feet) realizes a much higher level of efficiency. This helps minimize the environmental footprint of new transmission lines.

This comparison is also important in terms of cost. Use of 765-kV technology allows transmission builders to take advantage of economies of scale. As shown in Exhibit 2, 765-kV construction is only 29% of the cost of 345-kV and 38% of the cost of 500-kV for a comparable system in terms of capacity. Building 765-kV transmission would represent a strategic decision to strengthen the system beyond near-term needs with ample capacity to accommodate both future load growth and operating uncertainties intrinsic in competitive markets.

TRANSMISSION NEEDED TO DELIVER 2,400 MW OVER 100 MILES

Based on Surge Impedance Loading (SIL)*

	765-kV	**500-kV**	**345-kV**
Conductors Per Phase	6-Bundle	3-Bundle	2-Bundle
SIL Per Line	2400 MW	910 MW	390 MW
Lines Required For 2,400 MW Capacity	1	3	6
Width Required	200 ft.	600 ft.	900 ft.
Avg Cost Per Mile For 2,400 MW Capacity **	$2.6 MM	$6.9 MM	$9.0 MM

* Surge Impedance Loading is a measure of relative line loadability at the reactive power balance point without voltage support. Thermal capacities vary; e.g. 765-kV can carry well over 4,000 MW, 500-kV can carry over 2,000 MW.

** Average single-circuit construction costs in 2007 dollars; rural terrain with rolling hills; includes siting and right-of-way costs; excludes station costs.

Exhibit 2: Cost comparison for equivalent capacity of EHV AC transmission lines.

Line Losses

There is a need to capitalize on what has been learned in terms of applying system level design techniques for enhancing efficiency. Traditionally this has been viewed from two vantage points. Efforts have been made to improve system efficiency from a demand side or consumption stand point and also to improve the resources that generate energy to improve their overall efficiency. One very critical element for increasing efficiency - the delivery system - has largely been overlooked. A new EHV infrastructure would facilitate the use of the latest transmission technologies, maximizing the performance, reliability, and efficiency of the system.

Similar to any energy-related process, a certain amount of energy is lost during the transport of electricity. This is known as line loss and, in the case of electric transmission, occurs mainly through heat dispersion. The amount of line loss of a transmission line is proportional to the square of the current flowing in the line, as well as the physical characteristics of the conductor itself (material resistance, length, etc.). Exhibit 3 shows the relative losses for typical 765-kV, 500-kV, and 345-kV lines at various levels of power flow. The overall level of energy generation required can be significantly reduced by utilizing higher voltages, especially over long distances. It should be noted that HVDC lines are also highly efficient in this regard, but experience high levels of energy losses through the AC/DC conversion process thus offsetting this benefit for all but very long lines.

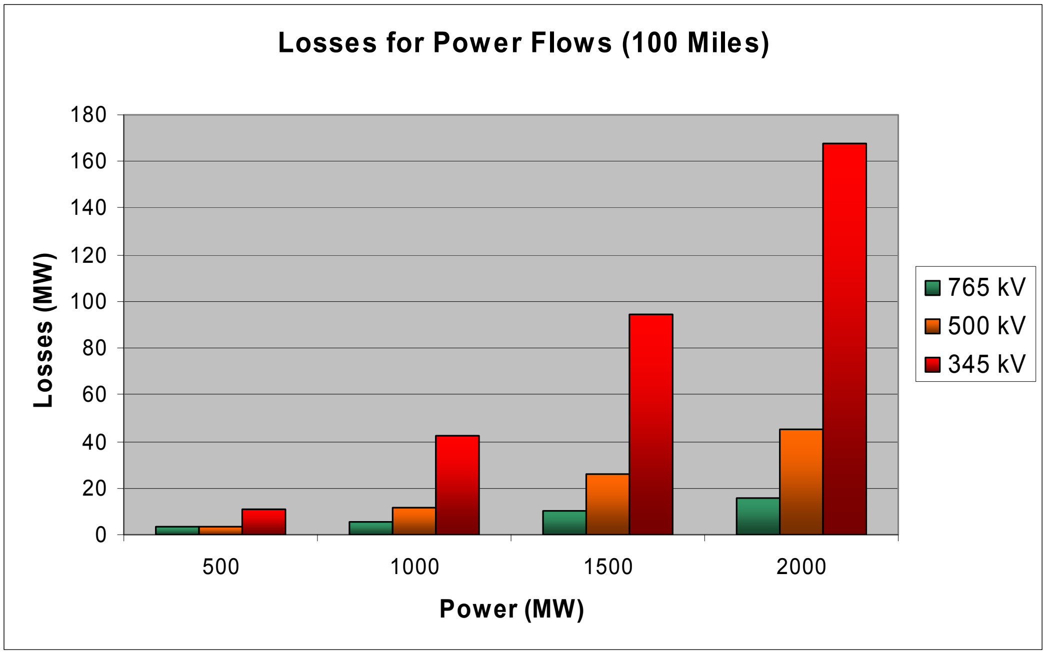

Exhibit 3: Relative line losses for various transmission voltages.

The national interstate highway system unloaded the U.S. route system significantly allowing the existing highway system to be upgraded to better serve local traffic or retired when not needed. Likewise, a 765-kV overlay can unload the lower-voltage transmission system, resulting in more efficient utilization of existing infrastructure. For example, some of the recent 765-kV projects proposed by AEP would unload the underlying system such that hundreds of megawatts (MW) of power (equivalent to a power plant) could be saved at peak demand periods and also provide associated energy savings every hour of every year.

Enabling Clean Energy

One of the significant challenges associated with the interconnection of renewable energy is that a signification portion of our natural renewable energy resources are located in remote areas where there is a weak (if existent at all) transmission system and where there is insufficient demand to consume the energy produced. This combined with the natural variability of some renewable technologies means that renewable resources also need to be balanced with a sufficient mix of other energy sources. Thus, a robust transmission system is needed to move electricity to areas of the country that can use the renewable energy and to bring electricity generated by other sources to renewable-rich areas during those times when the wind doesn't blow or the sun doesn't shine. The current system cannot perform this delicate balance. Only a robust backbone transmission system can provide the ability to share generation resources across broad regions, thus enabling greater diversification of supply and demand.

In early 2007, AEP participated in an exploratory effort led by AWEA to develop a conceptual transmission plan that would enable 20% of the energy in the United States to be supplied by wind. This is no simple task, as 20% of the nation's energy roughly equates to 350,000 MW of generation. With the aid of a number of experts from different fields within the industry, a plan supporting the development of a 765-kV interstate transmission network to achieve 20 percent wind generation penetration was developed. The 765-kV transmission network was conceived based upon (1) the locations of high-potential wind resources[3], (2) the locations of populated areas (load centers) across the country, (3) the location of existing or planned lines and stations, and (4) the need to economically connect any number of different generating plants and deliver energy from these locations to these load centers. In general, these principles describe the universal need of most new generation resources.

The result of this effort is shown in Exhibit 4. Though this is a conceptual configuration, this transmission network would consist of approximately 19,000 miles of 765-kV transmission lines at a cost of $60 billion.[4] It is estimated that this system could facilitate up to 400,000 MW of new wind generation, achieving AWEA's goal of 20%. While this system was designed toward the goal of 20% wind, other renewable and clean-generation technologies could use the same transmission infrastructure. Though conceptual in nature, this plan demonstrates the relative scale of transmission development required to meet aggressive clean-energy goals. (Note: Because this effort focused on wind specifically, no 765-kV lines were proposed for the southeastern United States as the region is largely deficient in significant, developable wind resources.)

---

[3] "Composite Wind Resource Map," U.S. Department of Energy National Renewable Energy Laboratory, http://www.nrel.gov, April 19, 2007.

[4] Assumes $2.6M/mile for 765-kV line plus 20% for station and other integration costs in 2007 dollars.

A system of this design provides additional efficiencies. As described earlier, one of the most significant advantages of using 765-kV is the significant line loss savings that would be realized. Over the areas covered with the overlay, the highest voltages currently deployed are typically either 345-kV or 500-kV.[5] Assuming an average transfer of power from these lower voltage systems to a 765-kV system, approximately 5,000 MW to more than 10,000 MW of loss reduction could be achieved.[6] In other words, this 765-kV overlay could eliminate the need for 5,000 to more than 10,000 MW of generation from existing or new resources - a considerable increase in efficiency. This calculation is substantiated by detailed engineering studies of the Potomac Appalachian Transmission Highline (PATH) project and AEP's joint study with ITC*Transmission* for 765-kV expansion in northern Ohio and Michigan. These studies indicate a loss savings of over 200 MW and 250 MW respectively under peak conditions for the two individual projects.

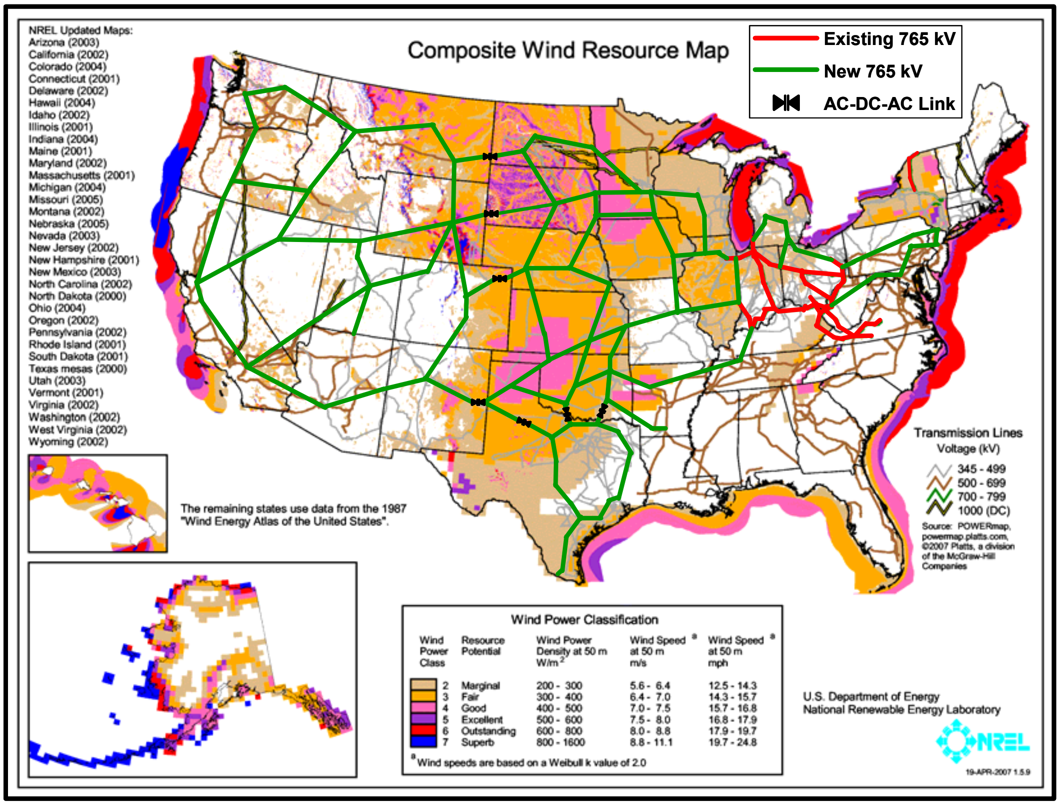

Exhibit 4: Conceptual 765-kV backbone system.

The annual energy savings associated with 10,000 MW in loss reduction would be on the order of 33,000,000 megawatt-hours (MWh). This energy loss reduction would achieve $1.7 billion per year in fuel cost savings at today's prices given the current generation mix. Additionally, as

---

[5] Approximately 69% 345-kV and 31% 500-kV in the regions traversed by the 765-kV overlay in terms of line miles. http://www.nerc.com/~esd/.

[6] For an average loading of 1,000-1,500 MVA.

load and generation increase in the future and more power would be shifted from lower voltage systems to the 765-kV system, the loss savings would increase. Additionally, the associated savings in CO_2 would be some 15,000,000 metric tons per year.[7] So, simply in terms of environmental optimization, a 765-kV overlay would, on its own, provide substantial benefits.

There are also significant generating capacity savings that the 765-kV network could achieve through "reserve sharing" at a national level. Today, each region has a reserve requirement, based on its own calculations, typically designed to maintain a loss of load expectation of no more than one day in ten years. Generally the requirement is about 15%. Today, this calculation does consider assistance available from neighboring systems, but the contribution is not typically significant due to weak transmission ties between the regions. If the proposed 765-kV transmission overlay were constructed, the resulting network would be strong enough to enable regions to "lean on" one another with more certainty and for larger amounts during peak times. The diversity in generation resources as well as the timing of regional peak loads would serve to further reduce the overall reserve margin. A reduction from 15% reserve on a regional basis to 15% reserve on a coincident peak (national) basis translates to approximately 30,000 MW of capacity. Even assuming that only a third of the reduction could be achieved, the savings would be 10,000 MW. The annualized cost reduction for 10,000 MW equates to approximately $900 million per year in savings.[8]

An interstate transmission system can also broaden the effect and reach of demand response and other benefits. Imagine if more than 100 million consumer meters were enabled to allow imperceptible automated demand changes that in aggregate could lower load during peak conditions. Imagine wind energy in North Dakota charging energy storage devices in Florida. Imagine taking advantage of the load and time difference between California and New York. Imagine the removal of barriers to access and operation of all aspects of energy supply and demand. Imagine.

Building Interstate Transmission

Moving the interstate transmission superhighway concept to reality is no simple task. It requires a fundamental shift in the way that the transmission system is planned and built. There are currently positive developments toward this goal. One of the most significant efforts is the Joint Coordinated System Plan (JCSP). The members of the JSCP include planning staff and other stakeholders from Regional Transmission Organizations (RTOs) including the Midwest ISO (MISO), PJM Interconnection, Southwest Power Pool (SPP) and Tennessee Valley Authority (TVA). The JCSP is responsible for the development of coordinated inter-regional system planning studies for a large portion of the Eastern Interconnection. (Note: The U.S. grid is comprised of three interconnected systems: east of the Rockies, west of the Rockies, and most of Texas). These studies, currently underway, address known state Renewable Portfolio Standard (RPS) requirements, potential high-percentage wind development scenarios, and future environmental and regulatory uncertainties. This is important, as these neighboring entities are

---

[7] Based upon energy reduction of 33,000,000 MWh on today's generation mix (the lower 48 states excluding Florida, New York, and New England).

[8] Based on the cost of a set of new combustion turbines today, 14% carrying charge rate, and $6/kW-year variable O&M. This equates to approximately $86/kW-year.

looking at the transmission system on an interstate and national level, while at the same time addressing relevant shifts in the generation mix toward generation technologies with lower emissions.

At the regional and local levels, several RTOs and individual companies are developing transmission projects independently. AEP continues to encourage 765-kV development and has proposed projects in partnership with several other utilities within PJM, Electric Reliability Council of Texas (ERCOT), SPP and MISO. In addition, SPP recently issued a proposal for a 765-kV overlay to address reliability and encourage wind generation development. Other utilities throughout the country also are developing similar plans. While the renewed interest in transmission development is encouraging, it is imperative that these individual plans are designed within the context of a common transmission vision for the benefit of the entire U.S. grid. Otherwise, there is risk of continued piecemeal designs which lack the benefits of a cohesive, integrated plan.

Significant obstacles and challenges persist in the move from planning to implementation. Large-scale transmission projects typically cross various jurisdictions - states, utilities, RTOs - and the questions of siting, investment, cost allocation, and cost recovery must be addressed. Different jurisdictions have different mechanisms for cost allocation. AEP believes EHV transmission, which provides a number of benefits over broad regions, should be socialized across a broad area. This helps minimize the impact on any one region or any one customer group. One vital concern is that cost recovery differs from state to state, and often regulatory decisions delay the commencement of a project. This uncertainty increases the financial risk, which must be borne by the companies building the projects. To promote timely investment in large, long-term transmission projects, it is imperative that these regulatory issues are promptly resolved at a national level. Financially speaking, if adequate cost recovery mechanisms are in place, transmission investment will follow. AEP and its partners have demonstrated the willingness to invest in transmission, with federal support and incentives key to driving this investment.

There are significant advantages associated with ensuring that the U.S. energy system as a whole is designed with a goal of maximizing efficiencies at all levels of the system: production, delivery, and consumption. There is little question that the broad integration of large-scale, clean energy technologies will require an advanced transportation system. Yet, greater access to renewable resources is certainly not the only driver for a robust EHV network. The network in and of itself would improve the overall performance and efficiency of the U.S. electricity system as a whole. Problems exemplified by the 2003 blackout were in fact related to an over-reliance on lower voltage transmission systems. At a national level, lower voltage transmission networks are becoming stressed and operating closer to their operating limits more and more often. Addressing this issue through the use of an EHV overlay ultimately can improve the reliability of the system while providing the platform for clean-energy integration. When viewed in the broader context of energy security and climate change, the case for robust interstate transmission is apparent. We must challenge our current planning horizons, recognize the value of EHV transmission infrastructure, and start paving a path to encourage and propagate the right long-term solution.

To see the vision, we only need to look no further than the development of the national interstate highway system and the economy and security it enabled for our nation.

##########