# Interstate Transmission Vision for Wind Integration

## I. Introduction

American Electric Power, working at the request of, and in partnership with, the American Wind Energy Association (AWEA), presents a high-level, conceptual interstate transmission plan that could provide a basis for discussion to expand industry infrastructure needs in the future. AEP believes that expansion of Extra High Voltage (EHV) interstate transmission systems provides increased reliability, market efficiency, environmental optimization and national security for the benefit of electric customers across the United States.

AEP currently owns two wind farms in Texas with a total capacity of 310 MW and has long-term agreements to purchase 467 MW of output from wind farms in Oklahoma and Texas. We support federal and state policies that reduce electricity production costs by facilitating deployment of these technologies, such as production tax credits and assurances from state regulators for recovery of investments. However, AEP does not support a national mandate that stipulates a Renewable Portfolio Standard (RPS) in the overall electric generation resource mix.

The nation’s transmission system is at a critical crossroads. The United States continues to experience transmission bottlenecks that compel the excessive use of older, less efficient power plants. Transmission grid capacity constraints must be eliminated to ensure a fair, vibrant and open market that gives us the flexibility to deliver economic and environmentally friendly energy to consumers.

AEP believes the nation’s transmission system must be developed as a robust interstate system, much like the nation’s highways, to connect regions, states and communities. Our highly efficient and reliable 765 kilovolt (kV) network provides a strong foundation for this system because it is the most efficient, proven transmission technology available in United States.

The hope is that this paper will promote discussion and set the stage for action.

## II. Executive Summary

Some experts believe the U.S. offers quantities of wind energy resources well in excess of future projected electricity needs. One of the biggest long term barriers in the adoption of wind energy to meet this growing demand is the physical limitations on the nation’s current electric transmission system. The nation's bulk transmission system is currently inadequate to deliver energy from remote wind resource areas to electrical load centers; located mainly on the East and West coasts. AEP believes that this barrier can be overcome by building transmission infrastructure that will enable wind power to become a larger part of the nation's power generation resource mix. This transmission system expansion will bring many additional societal benefits, including increased reliability and greater access to lower cost and environmentally friendly resources.

This conceptual transmission plan is illustrative and should be treated as such. AEP and other power industry leaders believe 765 kV in particular has many benefits over other options. There are, however, many possible configurations that could be leveraged to integrate wind and other resources. The goal is merely to present this proposal as one possible scenario to illustrate the potential that exists. Additionally, the intent of this visionary plan is to provide an example that encourages the type of thinking and, most importantly, consensus and action necessary to bring transmission and wind generation together on a national scale.

The result of this effort, shown in Exhibit 1, is a theoretical interstate 765 kV electricity transportation system that encompasses major portions of the United States connecting areas of high wind resource potential with major load centers. It is projected that an interstate EHV transmission system could enable significantly greater wind energy penetration levels by providing an additional 200-400 GW of bulk transmission capacity. The total capital investment is estimated at approximately $60 billion (2007 dollars). While it is by no means the total solution, this initiative illustrates the opportunities that exist, and what might be possible with adequate cooperation, collaboration, and coordination – "3Cs."

This report describes the data and methodology used in developing this plan, costs, benefits and wind deployment potential from the plan, and the efforts that will need to be undertaken to make the visionary concept a reality.

## III. Background

This endeavor is a derivative effort associated with a joint study involving AWEA, U.S. Department of Energy (DOE), and National Renewable Energy Laboratory (NREL). This study is committed to developing an implementation plan that would enable AWEA's proposal to provide up to 20% (approximately 350 GW) of the nation's electricity from wind energy.

AEP, along with members of several other wind, electric utility, RTO, and governmental organizations, was invited as a consultant to provide guidance and insight in regard to transmission. Though AEP does not support RPS mandates or penalties for not achieving mandates, AEP does support enabling renewable generation through transmission development and goals toward that end. Transmission infrastructure is a critical component in the development of wind generation, in particular on a national scale with such aggressive goals. It is this relationship that compelled these organizations to collectively develop an illustrative vision for the bulk transmission system to satisfy this target.

## IV. Expanding 765 kV Technology

The power grid in much of the U.S. today is characterized by mature, heavily-loaded transmission systems. Both thermal and voltage-related constraints affecting regional power deliveries have been well documented on systems operating at voltages up to, and including, 500 kV. While various mitigating measures are being proposed and/or implemented, they are largely incremental in scope and aimed at addressing specific, localized network constraints. Incremental measures are a deliberate means of shoring up an existing system in the near-term, but certainly do not facilitate the incorporation of renewable energy and other generation resources on the scale required to meet the proposed goal. In the longer term, a mature system facing growing demands is most effectively strengthened by introducing a new, higher voltage class that can provide the transmission capacity and operating flexibility necessary to achieve the goal of a competitive electricity marketplace with wind power as a major contributor. In addition, a new high voltage infrastructure would facilitate the use of the latest transmission technologies - maximizing the performance, reliability, and efficiency of the system.

The existing AEP 765 kV system provides an excellent platform for a national robust transmission infrastructure. The use of 765 kV AC technology would enable an expansion into a new high-capacity bulk transmission grid overlaying the existing lower voltage system, with both systems easily integrated where so required. By contrast, traditional DC technology is generally limited in its application to point-to-point transmission. Wind generation resources often cover a wide geographic area, and the cost to create multiple connections to a DC line could be substantially higher. A 765 kV AC network would allow for less complicated future connections of resources and integration into the underlying system. This type of integrated AC grid with ample capacity for future growth provides a solid foundation for reliable service and ease of access to all users. Furthermore, this network frees up capacity on lower voltage systems such as 500kV, 345 kV, and 230 kV. This is particularly important as this additional capacity allows operational and maintenance flexibility, as well as the ability to connect new generation resources onto the underlying system.

To assess the load carrying ability, or loadability of a high voltage transmission line, the concept of Surge Impedance Loading (SIL) is commonly used.[1] SIL is a convenient yardstick for measuring relative loadabilities of transmission lines operating at different voltages, and is that loading level at which the line attains reactive power self-sufficiency. For example, an uncompensated 765 kV line has a SIL of approximately 2400 MW. By contrast, a typical 500 kV line of the same length has a SIL of approximately 910 MW and a 345 kV line approximately 390 MW. The relative loadabilities of 765 kV, 500 kV, and 345 kV considering 150 miles line length (from the

[1] "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.

St. Clair Curve), are 3840 MW, 1460 MW, and 620 MW, respectively. It is apparent that a 765 kV line, 150 miles in length, can carry substantially more power than a similarly situated 500 kV or 345 kV line. Generally, about six single-circuit (or three double-circuit) 345 kV lines would be required to achieve the load carrying ability of a single 765 kV line. Relative loadabilities of the transmission lines also can be viewed in terms of transmission distances over which a certain amount of power, say 1500 MW can be delivered. For a 765 kV line, this loading represents approximately 0.62 SIL (1500/2400 = 0.625) which, according to the St. Clair Curve, can be transported reliably over a distance of up to 550 miles. By contrast, a 345 kV line carrying the same amount of power can transport reliably only up to 50 miles; this distance would increase to about 110 miles for a double-circuit 345 kV line.

Additionally, a line's capability can be increased further with adequate voltage compensation through the use of devices such as Static Var Compensators (SVC). High Surge Impedance Loading (HSIL) technology at 765 kV could also be considered. While HSIL lines have not been employed in the United States, studies indicate these lines could provide additional capacity with a relatively modest increase in cost.[2] Further research and development into these and other promising technologies is particularly important in order to create the most advanced and reliable future transmission system.

A further benefit of the use of 765 kV lines is the reduced impact on the environment. As stated above, one 765 kV line can carry a substantially higher amount of power than transmission lines operating at lower voltages. For instance, a single 765 kV line can carry as much power as three 500 kV lines or six 345 kV lines. The result is that fewer lines need to be constructed and less right-of-way clearing necessary compared to lower voltages for the same power delivery capability. Use of higher voltages also results in a more efficient system. By moving power off the lower voltage systems having higher resistance and onto the 765 kV, real and reactive power losses are reduced. It can also be demonstrated that a 765 kV line incurs only about one-half of the power losses of a six-circuit 345 kV alternative, both carrying the same amount of power.[3] This reduction in transmission losses will not only reduce overall energy consumption across the system, but also the need for generating capacity additions, resulting in a significant reduction in capital requirements, fuel consumption, and emissions.

## V. Methodology

In developing this conceptual 765 kV overlay, it is necessary to make a number of significant assumptions. While the routes and connections are derived based upon engineering judgment, the impact of the proposed overlay would require significant additional study by a number of different stakeholders. In addition, the transmission corridors shown on this diagram are not meant to preclude or replace any proposed

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[2] "MTEP06 Midwest ISO Transmission Expansion Plan," The Midwest Independent Transmission System Operator, Inc., February 2007 Revision, December 2006.
[3] "AEP Interstate Project: 765 kV or 345 kV Transmission," American Electric Power, April 24, 2007.

projects. Rather, it is meant to suggest one possibility that is believed to satisfy the goal of connecting areas of high wind potential with load centers across the country.

Our analysis relied on input from the on-going study, wind resource maps developed by the NREL, and individual contributions from other participants.[4] From this information, areas of high wind potential as well as cost-effective transmission corridors to major load centers were identified. Other existing transmission studies were also relied upon as pertinent sources. In many cases, these existing proposals include more detailed analyses and provided sound technical supporting information. For example, in the case of Midwest ISO's MTEP06 report and the proposal for the Texas Competitive Renewable Energy Zone (CREZ) initiative produced by Electric Transmission Texas (ETT- AEP joint venture with MidAmerican Energy Holdings Company), actual study of wind integration using 765 kV was performed.[5] These reports offered qualified information to help formulate the overall plan. Furthermore, a number of other projects have been proposed in other areas of the country, including several west of the Rocky Mountains. While these projects do not necessarily consider use of 765 kV, they do identify corridors where additional transmission is needed.

The vision map was created using the following process:

1. Identify and plot the existing 765 kV system and other 765 kV proposals to use as a foundation for expansion.
2. Using other proposals, determine corridors that have been identified as lacking transmission capacity but may not have been considered for 765 kV.
3. Identify major load centers and areas of high wind potential. Create links between areas without proposed transmission development that are determined to be cost-effective.
4. Connect the proposed 765 kV segments at strategic locations to form an integrated 765 kV network overlay that makes sense from a high level transmission planning and operations perspective. These locations would be substations, existing or new, that best allow dispersion of power into localized areas.

It is expected that this 765 kV overlay could provide enough capacity to connect up to 400 GW of generation. This was calculated by dividing the 765 kV network into loops and nodes where potential wind generation connections are expected. Each of these connections would be required to have two or more outlets on the 765 kV, and therefore would permit a level of generation equal to the capability of a single 765 kV line (allows outage of the other outlet). For the proposed system as shown in Exhibit 1, there are approximately 55 such potential connections (of course, in reality there would likely be many more connections in smaller incremental sizes). Since the length of these lines varies, assigning a specific SIL value to the overall system can be complicated.

[4] "Composite Wind Resource Map," U.S. Department of Energy National Renewable Energy Laboratory, http://www.nrel.gov, April 19, 2007.
[5] "Texas CREZ and Long Term Needs, A Comprehensive Transmission Proposal by Electric Transmission Texas (ETT)", Electric Transmission Texas, LLC, February 27, 2007.

However, a typical 765 kV line has physical equipment limitations upwards of 4000 MVA and conductor limitations upwards of 10000 MVA. A loadability range of 3600-7200 MW (1.5-3 times base SIL) can be credibly assumed for a given line. This equates to a total generation connection potential of approximately 200-400 GW, with even higher levels achievable by utilizing proper technologies. This also does not account for displaced generation and additional capacity available on the lower voltage systems, which may augment this potential.

## VI. The Conceptual Plan

The result of this process is a 765 kV backbone system that provides cost-effective connections from areas of high wind potential to major load centers. Furthermore, the overlay would provide significant reliability benefits to the overall transmission system in these areas. Exhibit 1 shows the theoretical 765 kV backbone transmission system as developed in this effort. The base graphic on the map is the Composite Wind Resource Map developed by the NREL. The color contours on the map show the wind power density and subsequent resource potential across the country. Transmission lines 345 kV and above are shown with the existing 765 kV system highlighted in red. The conceptual 765 kV overlay expansion is shown in green. DC connections between the regional interconnections are maintained, though optimal integration of these resources as proposed in this vision may dictate future synchronization of these areas.

From a high level, this visionary concept would provide maximum access to wind resources throughout the country with cost and transmission reliability given appropriate consideration as well. Notably, connecting the study's target goal of 350 GW could be attainable with this plan, over time. While this is simply one of any number of designs that could be considered, it is believed that a national 765 kV plan of this approach would create a robust platform increasing access to renewable energy as well as facilitating a competitive energy marketplace.

Because the southeastern United States is deficient in significant, developable wind resources, no 765 kV lines have been proposed for that region. While transmission is needed both for connection of wind resources and delivery of the resources to load centers, it is expected that the 500 kV system in this area could be enhanced for power delivery. Although it still may be worthwhile to extend 765 kV into these areas, it was decided that the added line mileage and cost associated with delivering the wind resources should be the subject of additional study.

The scenario presented consists of approximately 19,000 miles of new 765 kV transmission lines. This mileage includes existing 765 kV project proposals, such as ETT’s CREZ project in the ERCOT region and others in MISO and PJM. The rough cost of this plan is estimated to be $60 billion in 2007 dollars. This figure assumes a $2.6 million per mile 765 kV line cost, as well as an additional 20% for station integration, DC connections, and other related costs. These costs are ballpark estimates created without the benefit of detailed engineering and should be considered as such. Variations in labor, material, and right-of-way costs can cause these figures to fluctuate significantly.

There are considerable benefits from a plan of this scale. First, it provides the most efficient method of interconnecting remotely located wind generation resources with a system that is capable of delivering such resources to the areas that need them. Today's aging and heavily loaded transmission system is inadequate for this purpose, especially on the scale that is required to meet new renewable energy goals. An added benefit is a significantly higher capacity and dependable transmission grid. Problems including congestion, aging infrastructure, and reliability that plague the existing transmission system will be alleviated. A 765 kV overlay adds considerable stability to the overall transmission system and reduces the burden on the lower voltage system. In addition, operational flexibility is enhanced to a large extent, especially when outages are required for maintenance on parallel or underlying facilities. This may also permit some obsolete portions of the system to be retired, upgraded, or replaced. Finally, this system provides access to a broader range of generation, facilitating competition that will ultimately reduce costs to consumers.

## VII. From Vision to Reality

When much of the existing transmission infrastructure was developed in the mid-20th century, predictions of today's electricity demand were a fraction of what has been realized. In addition, few at the time would have foreseen a carbon-constrained future.

There are undoubtedly significant challenges to overcome before such an aggressive plan could become a reality. Transmission expansion requires certainty of cost recovery for investors, which is often not the case, especially when crossing state, company, and operational boundaries. As with most transmission development, the significant right-of-way requirements of this vision may certainly delay and obstruct its formation. It is also difficult to advance from incremental transmission planning to a larger long-term, multi-purpose strategic plan that crosses jurisdictional and corporate boundaries. One of the singular difficulties with wind generation is the remote location of the resources. Because of this, transmission and generation planning cannot be divorced from each other and limited to only few years in to the future, yet joint coordination of such requests is difficult and sometimes prohibited by regulatory edict. Steps in such a direction have been taken, but there is much more to be done.

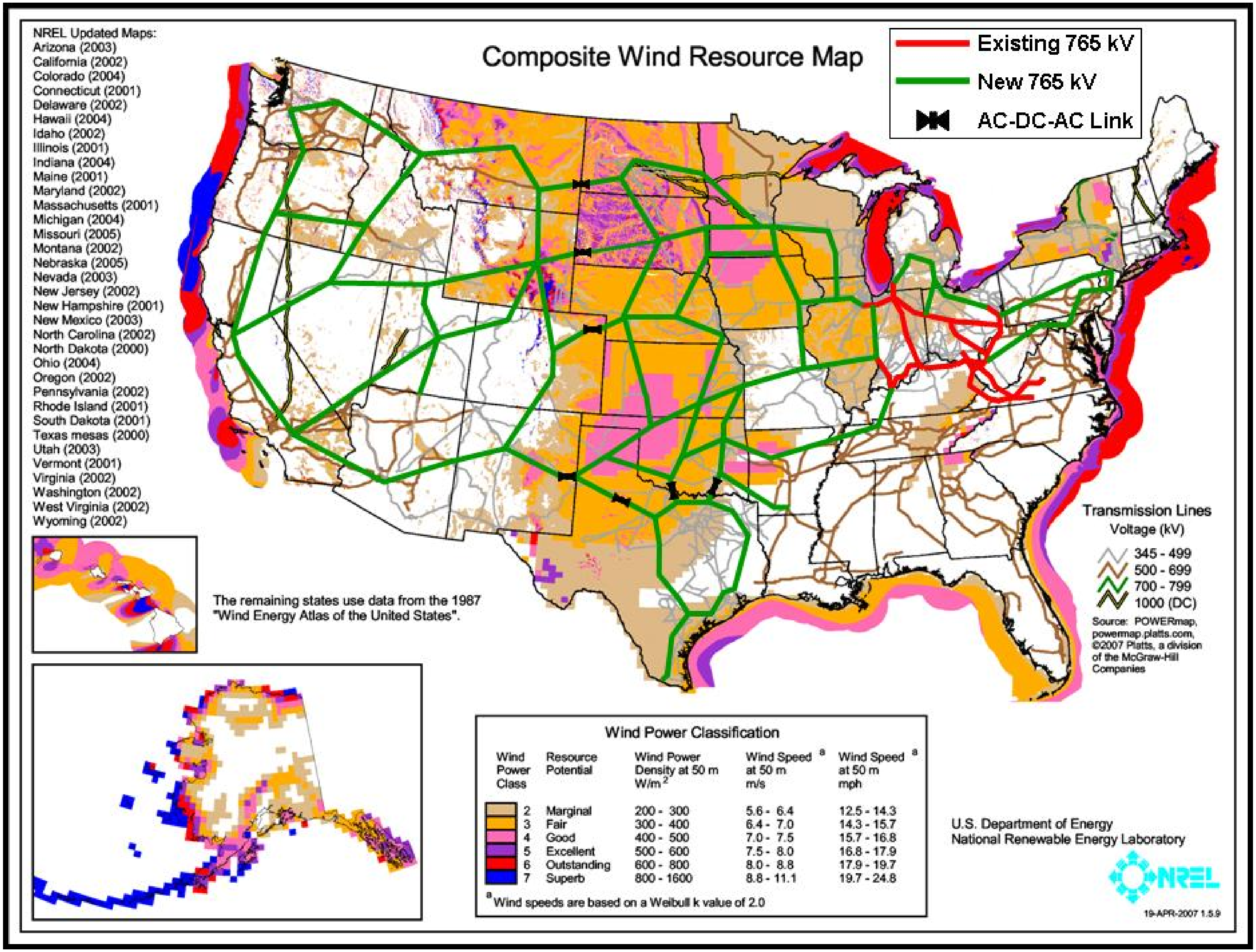


**Exhibit 1: Conceptual 765 kV backbone system for wind resource integration (edited by AEP).**