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Eastern and Western Interconnections Seam Study Update

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SUMMARY

The seam between the Eastern Interconnection (EI) and Western Interconnections (WI) in the U. S. was created in 1977, and is essentially unchanged. Given approved transmission projects, technology advances, aging infrastructure, increasing renewable penetrations, and the value of load and resource diversity across the existing seam, today's interconnections may not be optimal for the long term. The previous CIGRE US National Committee 2015 Grid of the Future Symposium paper "EI and WECC Seam Study" continued the interest and showed the need for a national grid study performed with new tools, harmonized models and synchronized datasets, combined with significant industry support to look to the future optimization value for the existing EI-WI seam.

The past decade has seen significant transmission expansion to integrate renewables and improve grid efficiencies. This effort was focused within planning regions and on coordinated activities among planning regions based on existing interconnections. Existing EI-WI back-to-back (B2B) High Voltage Direct Current (HVDC) tie interconnections, at 1,320 megawatts (MW) capacity total in the U.S., are limited in their ability to facilitate growth in Midwestern renewable resources; expanding these ties could significantly enhance these opportunities. Significant alternating current (AC) expansion is needed beyond the normal 10 year planning horizon absent any changes to the EI-WI seam facilities. It is critical that as infrastructure ages, current planned investments and reinforcements be strategically linked to longer term value propositions.

The U. S. Department of Energy (DOE) Grid Modernization Laboratory Consortium (GMLC) awarded in January 2016 the ***Interconnections Seam Study*** (Seam Study) with $1.2M over two years to convene industry and academic experts in power systems to evaluate the HVDC and AC transmission seam between the U.S. interconnections and propose upgrades to existing facilities that reduce the cost of modernizing the nation's power system. The DOE Labs supporting the Seam Study include National Renewable Energy Laboratory (NREL), Pacific Northwest National Laboratory

(PNNL), Argonne National Laboratory (ANL), and Oak Ridge National Laboratory (ORNL). Other participants of the leadership team for this strategic project include Iowa State University, Southwest Power Pool (SPP), Midcontinent Independent System Operator (MISO) and Western Area Power Administration (WAPA). Significant industry support is evidenced by active engagement and participation by all owner/operators of the existing B2B HVDC ties in the US along with dozens of affected entities and interested stakeholders. The Seam Study is leveraging knowledge from previous studies, using available data from recent stakeholder developed models, and developing advanced expansion planning and production cost modeling algorithms to evaluate the economic value of the combined EI and WI HVDC and extra-high voltage (EHV) AC expansion options. The Seam Study has a web page at http://www.nrel.gov/analysis/Seam.html.

Preliminary Seam Study co-optimized generation and transmission planning results are promising with each design showing benefits that exceed costs. Additional analyses will be needed to determine optimal plans for the EI-WI seam.

KEYWORDS

Transmission Planning – Aging Infrastructure – Renewable Integration – HVDC – Corridors – Seam issues – Production Cost Modeling - Geographic Decomposition - Diversity

BACKGROUND

The EI and WI span four time zones. Its demand for electricity is diverse in time and space and because of this it has depended on a variety of generating resources to grow the economy. Water has been a source of American electric power since the very beginning of our industry. After World War II, a variety of federal hydropower projects were developed along the Pacific Northwest, Rocky Mountains, and Southeast to bring water and electricity to the region. More recently, the production of renewable resources nation-wide has grown significantly as a result of increased wind and solar penetration levels. There is strong reason to believe this growth will continue, although the cost per MWhr of such growth will vary greatly, depending on the quality of the wind and solar resources that are employed, with the most economically attractive resources being in the central plains for wind and desert southwest for solar. Today, however, there exists a so-called “seam” between the EI and WI across which the East-West transmission capacity is extremely small. As a result, the benefit of the most economically attractive renewable resources is almost entirely limited to the region of the country in which these are built, since very little eastern resources cannot be transferred to the west, and very little western resources cannot be transferred to the east. This seam is shown by the dashed North-South line in Figure 1. A second dashed line shows the boundary of the ERCOT interconnection in Texas.

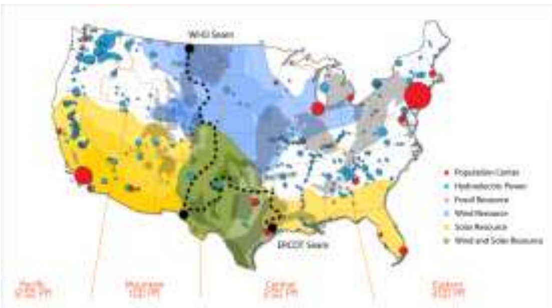

Figure 1. Resource and Load Diversity is Key

Figure 2. US Transmission System and B2B HVDC Ties

There does exist some U.S. transmission capacity between the EI and WI in the form of seven B2B high voltage direct current (HVDC) facilities having capacity of 1,320 MW. The location and capacity of the seven B2B HVDC ties in the U.S. that interconnect the EI and WI are shown in Figure 2.

As previously indicated, the 1,320 MW of cross-seam transmission capacity is very small compared to the size of the networks they connect—the EI is home to 800,000 MW of generating capability, while the WI has 200,000 MW of generating capability, showing that the current cross-seam transmission capacity is only a 0.1% of the nation's generating capability. In addition, these facilities, located strategically where the East meets the West, are aging and thus present a timely and impactful opportunity to modernize the U.S. electric grid.

System planners in central U.S.—utility executives, entrepreneurs and investors, land use authorities at the local, county and state level, as well as various utility industry regulators—are faced with a dilemma. On one hand, power system planners in this part of the country could act locally, and focus on their individual footprints, meeting their system demand as they see it. On the other hand, system planners could see a national opportunity to use the region's natural resources to reduce electricity costs and drive national economic growth. How large are the differences between these choices, and what are the options for getting the most out of the region's natural resources? To help answer these questions the Seam Study is analyzing four transmission designs to take advantage of the rich diversity in energy resources in terms of geographical location and technology type. All four designs economically compete for investments in wind, solar, and natural gas-fueled generation, and AC and DC transmission technologies throughout the country in response to growing demand, generation retirements, and increasing CO_2 costs. The four designs differ in terms of the nature of the cross-seam transmission capacity that is allowed. Design 1 provides a benchmark against which other designs are compared; this design allows the existing 1,320 MW of cross-seam transmission in the seven B2B ties, but it prohibits any cross-seam transmission expansion; Design 2a allows expansion of the seven B2B ties; Design 2b allows expansion of the seven B2B ties together with expansion of three cross-seam HVDC lines; Design 3 enables expansion along specified paths of a multi-terminal HVDC Macrogrid.

The purpose of this Seam Study update is to summarize the study methodology and provide high level, preliminary observations for Design 1, 2a, 2b and 3 based on initial reduced model test data.

STUDY METHODOLOGY

The Seam Study is projecting the value of the WI and EI B2B ties and potential upgrades due to the rich diversity of energy resources and consumption that exist between the interconnections. To capture and model this value a comprehensive economic and reliability analysis is performed on each scenario. The critical tasks in this analysis are:

- Develop and verify new wind, solar and load data
- Develop a new co-optimized transmission and generation expansion planning model with Iowa State University
- Develop a new production cost model
- Develop reliability models of the EI and WI

The current models and data have been updated to enable simulation of the 2024 through 2038 generation and transmission expansion planning horizon. The EI and WI combined detailed power flow and Production Costing Models (PCM) data were utilized to develop the reduced equivalent network model. The reduced equivalent network model was used in the co-optimized transmission and generation expansion model to develop the generation and transmission plans for the four design plans. The design plans were then mapped to the detailed PCM and evaluated using DOE high-performance computers. The final designs will go through AC power flow single contingency analysis to validate the design reliability performance. The final report is due October 1, 2017.

The coordination between the DOE Laboratories at NREL, PNNL, ORNL, ANL and Iowa State University with input and guidance from industry participants in performing these critical tasks is conceptually presented in Figure 3.

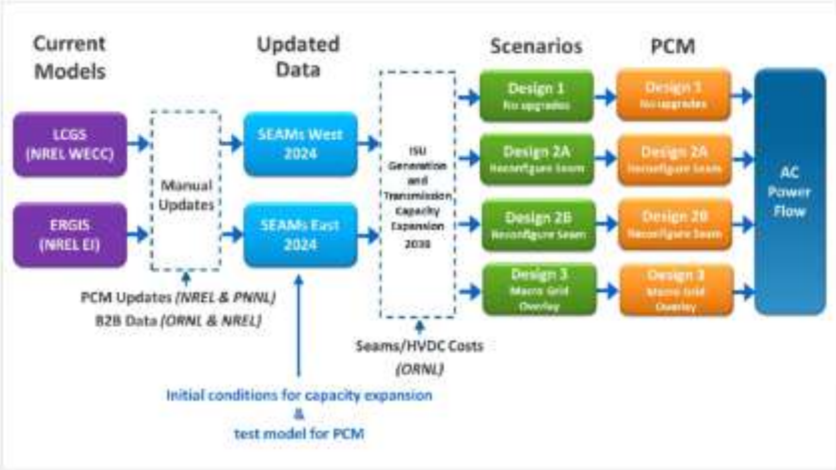

Figure 3. Seam Study approach scheme.

Develop and verify new wind, solar and load data

The engineering domains in this study include expansion planning, production costing, and steady-state power flow analysis over a future fifteen year planning horizon, 2024 through 2038. The co-optimized generation and transmission plan are developed using CGT-PLAN to determine the capital and operating costs for the years of 2024 through 2038.

The PCM analysis uses the Energy Exemplar Integrated electric power, gas and water simulation software PLEXOS to model and capture hourly unit commitment and 5 minute economic dispatch to estimate the value of avoided production costs for the study scenarios. Siemens Power Transmission System Planning Software PSS®E models are used to ensure EHV Interconnection single contingency (N-1) reliability for detailed AC power flow simulations.

Existing models and datasets were updated to provide consistent data between modeling domains. The 2012 wind resource data is from the NREL Wind Integration National Dataset Toolkit. The Wind Integration National Dataset (WIND) Toolkit is an update and expansion of the Eastern Wind Integration Data Set and Western Wind Integration Data Set. It supports the next generation of wind integration studies.

The 2012 solar data is from the updated National Solar Radiation Database (NSRDB). The current version of the NSRDB (v2.0.0) was developed using the Physical Solar Model (PSM), and offers users the latest available data (1998–2014). NSRDB comprises 30-minute solar and meteorological data for approximately 2 million 0.038-degree latitude by 0.038-degree longitude surface pixels (nominally 4 km^2). The area covered is bordered by longitudes 25° W on the east and 175° W on the west, and by latitudes 20° S on the south and 60° N on the north.

The load in the Production Cost Model (PCM) is from the Federal Energy Regulatory Commission (FERC) 2012 EIA 411 dataset. Harmonizing the resource and load data from a 2012 baseline is a milestone and significant value-add.

The detailed nodal model is the combined WECC Transmission Expansion Planning Policy Committee (TEPPC) 2026 - Western Interconnection and the Eastern Interconnection Reliability Assessment Group Multiregional Modeling Working Group (MMW) MMWG 2024 - Eastern Interconnection steady-state power flow models. The combined power flow model includes over 100,000 nodes, 14,100 generation sources, 53,500 loads, 126,300 branches, and 40,800 transformers. Its important to note that the detailed 2024 transmission model for WI includes the Energy Gateway projects as well as several other generation and transmission additions that will be included in the 2026 WECC TEPPC update.

Develop new co-optimized generation and transmission expansion model

Researchers at Iowa State University reduced the detailed WI-EI model to 169 nodes, 68 in EI and 101 in WI. The equivalent pipes between nodes model power flow impedance and capacity to provide realistic flow patterns in the co-optimized generation and transmission planning (CGT-PLAN) simulations.

All scenarios considered annual CO_2 cost rate of increase, fuel cost forecasts, generation investment base cost, technology maturation rates, transmission base costs, and generation and transmission regional cost multipliers. All costs are shown as net present value (NPV). Simulations were performed with 7 investment periods through 15 years. The model simulates Planning Reserve requirements, demand and distributed generation growth. State Renewable Portfolio Standards (RPS) is not enforced. Wind resource additions are based on 100 meter hub height data which significantly expands the range of high quality resources beyond the Plains to include much of the Midwest, as well as large portions of the Northeast US. The generation retirement criteria is if a unit is not dispatched at all in a given year, this it is retired in the next year.

All four designs utilize only HVDC in their cross-seam transmission facilities but identify necessary AC transmission needs within each interconnection; conceptual illustrations are provided in Figure 4. In Design 1, existing Seam B2B ties remained at existing capacity, but their flows were allowed to take full advantage of all economic opportunities including EI and WI diversity. In Design 2a, capacity of all B2B ties were allowed to grow as long as the economic benefits of that growth exceeded its cost as assessed within the optimization model. Design 2b was similar to Design 2a, except that cross-seam transmission growth could occur not only at the seven existing US ties but also at any of three HVDC lines having terminals interior to each respective interconnection. Although Designs 2a and 2b have not yet been explicitly tested for N-1 reliability, the fact that they contain 7 and 10 different cross-seam transmission paths, respectively, suggest that N-1 reliability may be satisfied in these designs with relatively little adjustment, particularly if no single path has significantly higher capacity than the remaining ones. Design 3, referred to as the macrogrid design, deploys an HVDC network spanning much of the nation, having three east-west paths, two north-south paths, and two spur lines. In Design 3, all HVDC transmission segments were allowed to grow, again as long as the economic benefits of that growth exceeded its cost. However, existing B2B ties were not allowed to grow. In addition, macrogrid segments were required to grow with equal capacity; this requirement, together with its topology, ensured the macrogrid design is self-contingent, i.e., it is explicitly designed to withstand loss of any single N-1 component. The HVDC line terminals in Design 2b and 3 are predetermined for these simulations which is not necessarily an optimal design.

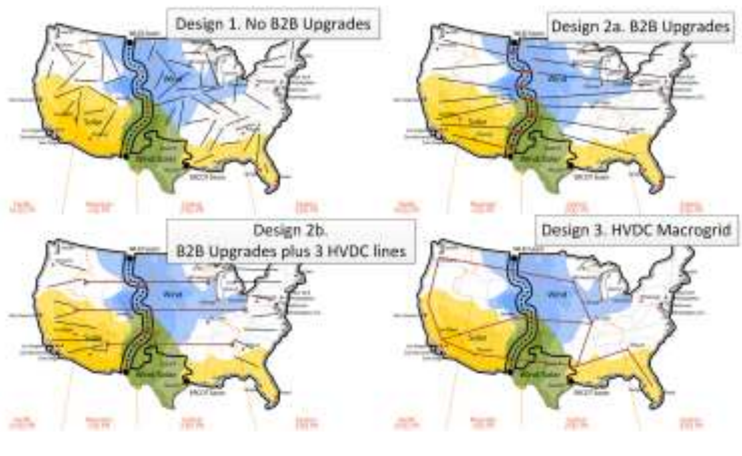

Figure 4: Conceptual illustrations of four cross-seam transmission designs

Preliminary CGT-PLAN results

The CGT-PLAN model was initialized using existing model data. The results in this paper reflect initial model findings from test data. The data used in obtaining the results reported in this paper are being updated, and new results are forthcoming. Therefore, the description of these results should be considered tentative and subject to change in the near future. The PCM will be updated using the final Generation and Transmission Plans from the CGT-PLAN model.

The model optimizes the cost of building transmission with wind and solar in regions of high resource quality against the cost of building lower CF wind and solar closer to the load centers, while accounting for benefits associated with diversity in dirunal peaks across time zones and diversity in annual peaks from one region to another. The three designs that provide additional cross-seam transmission have economic benefits that exceeds the cost of the cross-seam transmission investment. There are two main drivers for these benefits: 1. Wind energy moving from middle of US to the coasts and 2. Interregional sharing of capacity for planning reserves made deliverable by the cross-seam transmission designs.

In spite of non-negligible CO_2 cost (it increases at $3/metric ton/yr so that it is $45/metric ton in 2038), the CGT-PLAN model shows modest retirement of fossil generation, and it builds some gas. The model builds wind and solar to supply energy, but because of low capacity credits for wind and solar, the model retains many fossil units to benefit from their capacity contributions during peak periods although these fossil units supply very little energy during the year.

There are five large AC transmission reinforcements that occur in every design and every sensitivity:

1. Midwest-North flowing eastwards and a bit southwards.
2. Midwest-South flowing eastwards and both southwards and northwards.
3. West-Central flowing westwards and a bit southwards.
4. Southwest flowing westwards
5. Northwest flowing northwestwards.

Overall, the attractive wind (100m) and solar cost/performance attributes are main drivers to the generation investments produced by the model, so much so that gas price and CO_2 cost, though influential, are secondary.

Solar becomes very competitive with wind after 2030. We are not seeing large amounts of solar production moving across the Seam, although the expansion planning model might not be capturing the time-zone effect as well as the PCM will. By 2034 solar generation expansion is on par with wind generation expansion and exceeds wind growth through 2038.

Develop a new production cost model

The traditional PCM performs one optimization for the entire system. One drawback of the traditional approach is the results reflect overly optimistic representation of system flexibility. Another drawback is that non-linearities result in intractable solve time on detailed models. A new approach, Geographic Decomposition, had to be developed to handle the enormous amounts of data and calculations so solve the combined EI-WI PCM model. The benefits of Geographic Decomposition include separate optimization for each region, substantial reduction in solve time, and more accurate representation of regional flexibility constraints.

Develop reliability of the eastern and western interconnections

The PCM models test the economic value of each co-optimized generation and transmission design on detailed combined EI-WI models. The reason to develop steady state power flow models is to test the reliability of the design plans. The AC power flow analysis of each design is important to help stakeholders determine how to connect future lower cost renewable energy resources to the current US power grid.

WHAT IS NEXT?

Preliminary results of the Seam Study reduced co-optimized generation and transmission model show value for expanding the existing Seam between the EI and WI . These preliminary results demonstrate the value of and the need to continue investigations of additional scenarios to optimize seam designs. Future studies need to examine if expansion of B2B tie capacity at other locations is better given EHV developments near the seam between the EI and WI over the past 40 years, as well as approved projects being built to capture and deliver high quality renewables. Stakeholders have also indicated interest in looking at potential AC connections to bypass existing B2B ties although this is out of scope for this present Seam Study. The Seam Study data, models, and results will be used to facilitate the NREL North American Renewable Integration Study (NARIS). More details for NARIS are available at http://www.nrel.gov/analysis/naris.html.