SMARTransmission

Phase 1 Report
Strategic Midwest Area Renewable Transmission (SMARTransmission) Study

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Table of Contents

List of Figures

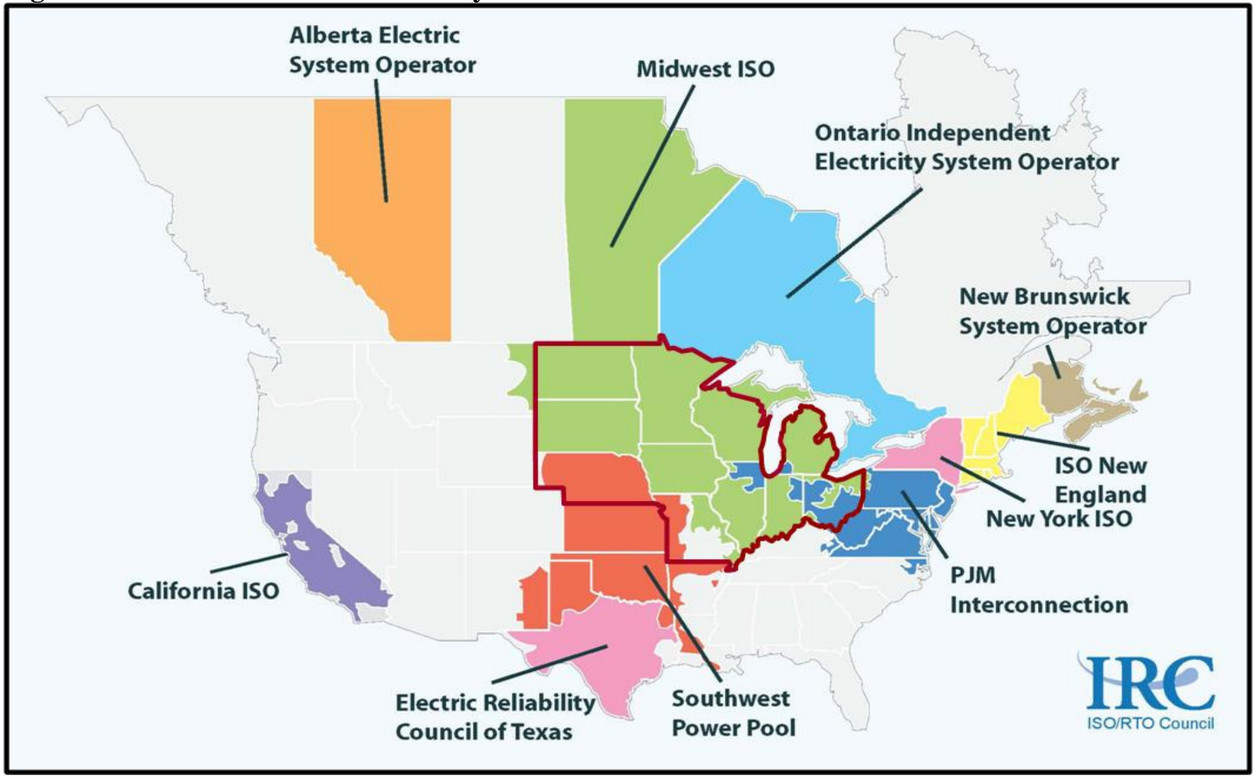
List of Tables

1 Executive Summary

The Strategic Midwest Area Renewable Transmission study, or SMARTransmission, was undertaken to investigate transmission overlay possibilities that will facilitate the development of Midwest wind energy generation and enable its delivery to the consumers within the study area. The study's primary goal is to develop a transmission plan that ensures reliable service, is environmentally friendly, and supports state and national energy policies. SMARTransmission focuses 20 years into the future and incorporates information from existing studies, as appropriate.

SMARTransmission is being sponsored by Electric Transmission America (ETA) – a transmission joint venture between subsidiaries of American Electric Power and MidAmerican Energy Holdings Company, American Transmission Company, Exelon Corporation, NorthWestern Energy, MidAmerican Energy Company – a subsidiary of MidAmerican Energy Holdings Company – and Xcel Energy. The sponsor group engaged Quanta Technology LLC (Quanta) to evaluate extra-high voltage (EHV) transmission overlays and provide recommendations for new transmission development. The study area covering portions of the Midwest ISO, PJM Interconnection and Southwest Power Pool footprints can be seen in **Figure 1-1**. Given the geographical proximity of the sponsors' respective systems, expertise in transmission operations, and the concentration of renewable resources within their footprints, the sponsors believe that a collaborative study is the most effective way to determine the study area's current and future transmission needs. Collectively, the sponsors bring unrivaled expertise to the needs of the Midwestern electric system.

Figure 1-1: SMARTransmission Study Area



SMARTransmission recognizes the critical role transmission infrastructure plays in the interconnection and delivery of generation resources and seeks to ensure that the overall system is efficient and capable of interconnecting wind and other generation resources. To this end, transmission needs were analyzed from a regional perspective over a study area that encompasses some of the nation's best wind resources. The information derived from reliability analyses is being used to recommend solutions for the expansion of EHV transmission, integrated with the existing transmission system in areas of North Dakota, South Dakota, Iowa, Indiana, Ohio, Illinois, Michigan, Minnesota, Nebraska, Missouri and Wisconsin.

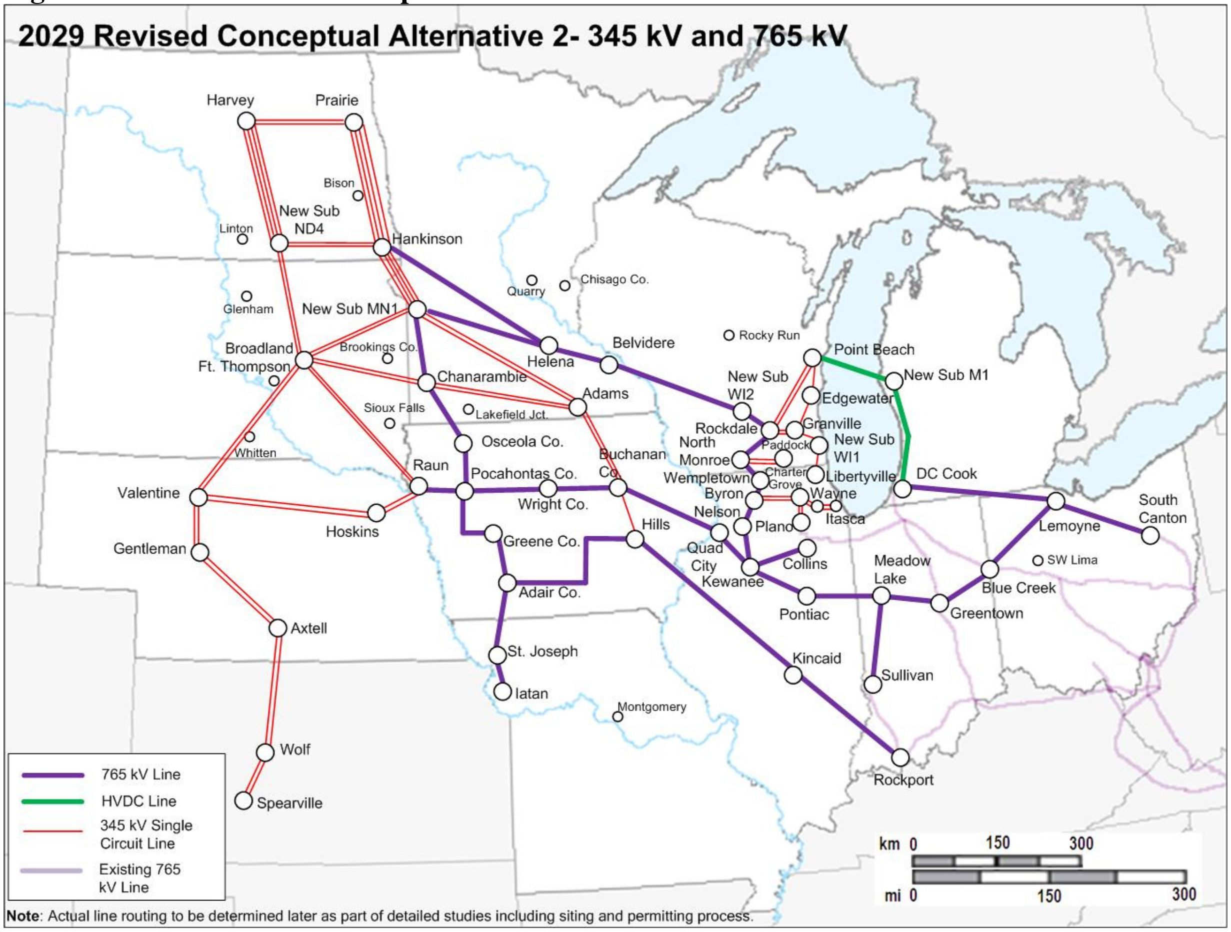
The SMARTransmission study transcends traditional utility and RTO boundaries. As a result, the study was designed to incorporate a high level of stakeholder input. Throughout the study process, the SMARTransmission sponsors have held open meetings where interested stakeholders had the opportunity to participate and provide input into the direction of the study. Over 100 participants representing investor owned utilities, state utility commissions, the Federal Energy Regulatory Commission (FERC), municipalities, wind developers, regional transmission organizations and others have participated in the open meetings. To further encourage widespread participation, the study sponsors established a website at www.smartstudy.biz to post meeting notices, study assumptions, milestones, deliverables and other pertinent information as well as to provide a venue for interested stakeholders to ask questions.

SMARTransmission is being completed in two phases. The first phase of the study was focused on identifying EHV transmission overlay alternatives and evaluating their cost and reliability performance, and the second will be used to compare the economic benefits of those alternatives. During the first phase of the study, the sponsor group designed eight conceptual EHV transmission overlay alternatives that would enable the integration of 56.8 GW of nameplate wind generation within the study area. The sponsors considered all voltages, including HVDC, when developing the eight conceptual EHV transmission alternatives. The 56.8 GW of nameplate wind generation generally reflects a federal Renewable Portfolio Standard (RPS) requirement of 20% with adjustments for those states that have approved RPS requirements or goals in excess of 20%. Of these eight alternatives, one was exclusively 345 kV, two were a combination of 345 kV and 765 kV, and five were exclusively 765 kV.

Based on performance and cost, three modified EHV transmission overlay alternatives were selected for futures and sensitivity analysis. The first potential alternative, shown in **Figure 1-2:** 2029 Revised Conceptual EHV Transmission Alternative 2, was primarily a combination of 345 kV and 765 kV facilities. The second potential alternative, shown in
Figure 1-3: 2029 Revised Conceptual EHV Transmission Alternative 5, was primarily 765 kV facilities. The third potential alternative, shown in **Figure 1-4:** 2029 Revised Conceptual EHV Transmission Overlay Alternative 5A - Includes HVDC, was primarily 765 kV with a long HVDC transmission line. These three EHV transmission overlay alternatives performed better in the reliability analyses than the other alternatives developed for the first phase of the study; however, this does not preclude different long-range projects that accomplish similar system performance to the projects in these alternatives.

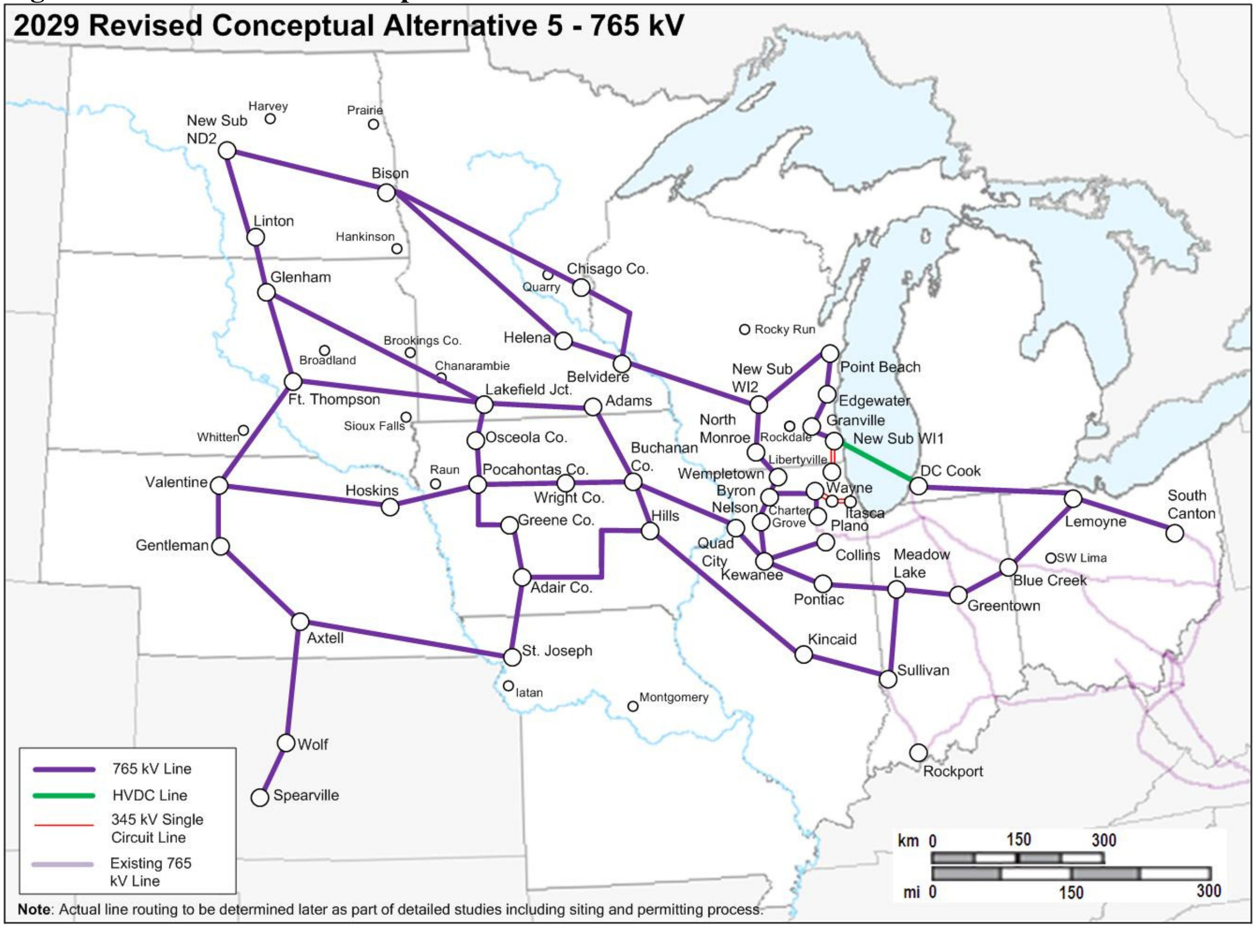
To help determine the prospective build out of the two potential EHV transmission overlay alternatives, the sponsor group developed a sequencing approach for 2019 and 2024. Actual sequencing of the potential EHV transmission overlay will be dependent on where and when wind generation is developed as well as the magnitude and distribution of load growth. The results have been shared with the Southwest Power Pool (SPP), Midwest Independent System Operators (Midwest ISO), PJM Interconnection, and Mid-Continent Area Power Pool (MAPP) to be used as input into their planning processes.

Figure 1-2: 2029 Revised Conceptual EHV Transmission Alternative 2



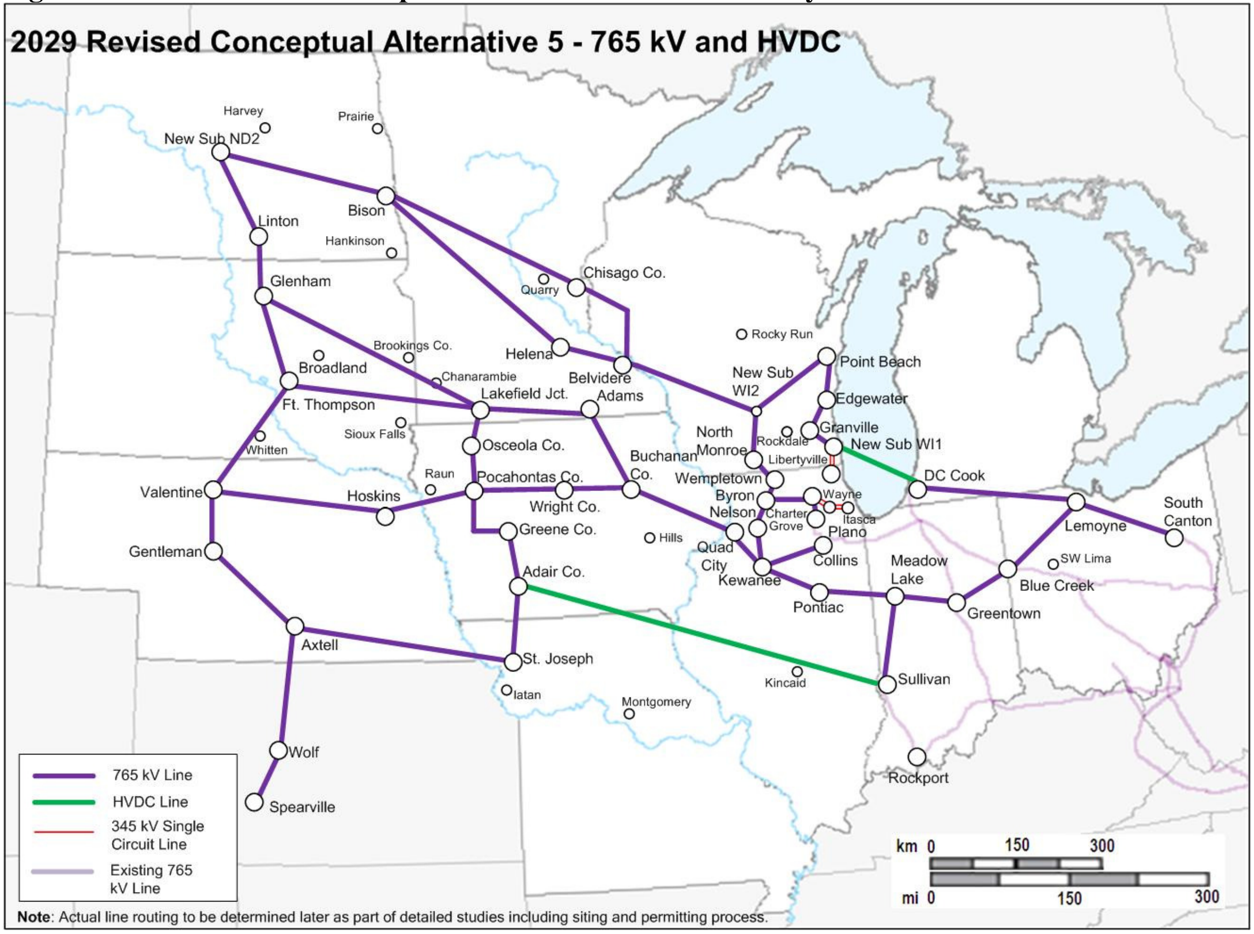
Note: Actual line routing to be determined later as part of detailed studies including siting and permitting process.

Figure 1-3: 2029 Revised Conceptual EHV Transmission Alternative 5



Note: Actual line routing to be determined later as part of detailed studies including siting and permitting process.

Figure 1-4: 2029 Revised Conceptual EHV Transmission Overlay Alternative 5A - Includes HVDC



Note: Actual line routing to be determined later as part of detailed studies including siting and permitting process.

2 Phase 1 Overview

New transmission is a critical component of enabling the United States to effectively use the country's abundant renewable resources. During Phase 1 of the SMARTransmission study, the Sponsor group evaluated eight conceptual EHV transmission overlay alternatives designed to enable the integration of 56.8 GW of nameplate wind generation within the study area. The 56.8 GW of wind generation generally reflects a federal Renewable Portfolio Standard (RPS) requirement of 20% and adjustments for states with approved RPS requirements or goals in excess of 20%.

In addition to considering RPS requirements, the sponsor group evaluated the wind generation potential of each state in the study area. This information enabled the group to quantify the transmission needed to enable the states to meet their RPS requirements and effectively use the country's natural resources. Of the eight conceptual EHV transmission overlay alternatives designed, one was primarily 345 kV, two were a combination of 345 kV and 765 kV, and five were primarily 765 kV.

To determine the best performing options, Quanta Technology completed cost and reliability analysis for each of the conceptual EHV transmission alternatives. Based on these results, the sponsor group chose three conceptual EHV transmission alternatives for additional analysis. Modified versions of Alternative 2 (345 kV/765 kV), Alternative 5 (765 kV), and Alternative 5A (765 kV with an additional HVDC line replacing one 765 kV line) were analyzed further using futures and sensitivities. The study analyzed high gas and low carbon futures with sensitivities for high and low wind generation, SPP imports, and high and low loads. This analysis showed that these three potential EHV transmission overlay alternatives work in the futures and sensitivity analyses with manageable contingencies and mitigations.

In addition to running the futures and sensitivity analysis, the sponsor group completed a sequencing analysis to determine the 2019 and 2024 build outs that would facilitate the development of the optimized 2029 potential EHV transmission overlay alternatives. The results of both the sequencing and the 2029 analysis will be shared with the Regional Transmission Organizations to serve as input to the regional transmission planning processes and to identify required projects. The timing and sequencing of these alternatives is intended to be flexible and can change based on local and regional needs.

3 Alternative Development

3.1 3.1 Wind Models

Wind generation assumptions were crucial to SMARTransmission's EHV analysis. Quanta Technology and the sponsor group evaluated state and federal RPS requirements, estimated wind nameplate potential, and the future energy contribution of wind farms to develop the wind assumptions used for the study.

3.1.1 State and Federal RPS Requirements

State RPS requirements call for states to obtain certain percentages of their retail energy sales from renewable sources by certain dates. Transmission will play an important role in enabling states to meet these requirements. The SMARTransmission RPS assumptions for 2029 reflect a federal RPS requirement of 20% with adjustments for those states that have approved RPS requirements or goals in excess of 20%. State RPS mandates used in this study were obtained from the Database of State Incentives for Renewable and Efficiency. This information is summarized in **Table 3-1.**

Table 3-1: Summary of State Renewable Portfolio Standards

State	Summary of RPS Requirements	SMARTransmission RPS Assumptions for 2029
Iowa	2% 2011 or 105 MW	20%
Illinois	25% by 2025	25%
Indiana	None	20%
Michigan	10% 2015	20%
Minnesota[1]	25% by 2025	27.5%
Missouri	15% 2021	20%
North Dakota	10% 2015	20%
Nebraska	None	20%
Ohio	25% by 2025	25%
South Dakota	10% 2015	20%
Wisconsin	10% 2013 20% 2020 25% 2025	25%

Based on the SMARTransmission RPS assumptions, the study sponsors determined the renewable energy requirements for each state as shown in **Table 3-2**.

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[1] Xcel Energy has a 30% RPS requirement and the rest of the state has a 25% RPS requirement. Because Xcel Energy is approximately half the load in the state, the RPS in Minnesota was assumed to be 27.5% for the entire state.

Table 3-2: Energy Requirement by State for Base Wind 2029

	IA	**IL**	**IN**	**MI**	**MN**	**MO**	**ND**	**NE**	**OH**	**SD**	**WI**
Federal 20% - State RPS - Utility RPS in %	20%	25%	20%	20%	28%	20%	20%	20%	25%	20%	25%
% of energy renewable from wind (MWh)	80%	75%	80%	80%	80%	80%	80%	80%	50%	80%	65%
Average Capacity Factor (Supplied from MISO 3 Year Capacity Factor Statistics	0.378	0.3	0.325	0.303	0.363	0.354	0.398	0.403	0.304	0.404	0.3
High Wind State- yes/no? (high wind state if capacity factor >36%)	Yes	No	No	No	Yes	No	Yes	Yes	No	Yes	No
Energy Growth (average US)	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.1%
Energy Usage by US State (MWh) / 2007 EIA	45,269,523	146,055,151	109,420,150	109,296,749	68,231,182	85,532,850	11,905,695	28,248,400	161,770,827	10,603,301	71,301,300
Total energy usage extrapolated assuming constant growth (billion MWh) (2029)	56,347,693	181,797,163	136,196,996	136,043,397	84,928,434	106,464,095	14,819,207	35,161,231	201,358,714	13,198,097	90,703,255
% for RPS renewable (MWh) -	11,269,539	45,449,291	27,239,399	27,208,679	23,355,319	21,292,819	2,963,841	7,032,246	50,339,679	2,639,619	22,675,814
RPS energy from wind (MWh)	9,015,631	34,086,968	21,791,519	21,766,944	18,684,256	17,034,255	2,371,073	5,625,797	25,169,839	2,111,696	14,739,279
Total	**172,397,256**										

3.1.2 Base Wind Nameplate Capacity

The sponsor group thoroughly evaluated the wind generation potential of each state in the study area since this information was necessary to quantify the transmission requirements that would enable the states to meet the RPS requirements in the study. The study team believed that the state wind potential should be based on consistent assumptions throughout the study area. In March 2008, the National Renewable Energy Laboratory (NREL) engaged AWS Truewind, LLC to develop wind resource and plant output data to be used for the Eastern Wind Integration Transmission Study (EWITS)[2]. SMARTransmission used the state wind capacities developed by NREL to allocate the wind generation potential in the study area to each of the states[3].

Table 3-4 shows the calculation for the nameplate wind capacity needed to meet state RPS requirements. These capacity requirements were based on a calculation that assumed wind energy would provide approximately 80% of the renewable requirements of each state. The remainder was assumed to be achieved through other means. This allows for a moderate amount of renewable energy to be sourced from non-wind energy sources. For those states with in-state renewable generation mandates or goals, SMARTransmission included the state-specific requirements. For example, Ohio requires at least 50% of its renewable energy requirement to be met by in-state facilities, while the remaining 50% is permitted to be achieved with resources that can be shown to be deliverable into the state. The 50% that could be generated outside of Ohio was allocated to other states within the study area. Similarly, Illinois has a provision that gives preference to resources within Illinois and adjoining states.

Existing wind generation was subtracted from the 2029 renewable energy requirement to establish the incremental wind generation needed. The incremental wind generation in the study area was then allocated among the states in proportion to the wind capacity of the NREL Selected Sites shown in **Table 3-3.** Column D of **Table 3-4** shows that Iowa and North Dakota already meet approximately 80% of the assumed 20% Federal RPS requirements that were modeled because the existing wind installations exceed the 2029 requirements. Column I shows that, by 2029, there will be enough excess wind energy in Iowa, North Dakota, Nebraska, and South Dakota to satisfy the requirements of those states that cannot meet their renewable energy requirements with in-state resources. The total nameplate wind generation value for all the states in the study area is 56.8 GW. This includes 9.3 GW of wind that was online as of May 2009. **Figure 3-1** shows the assumed locations and magnitudes of the wind farms in the study area.

Table 3-3: Nameplate Wind Generation Potential by State

State	NREL Capacity Distribution (MW)
Iowa	52,575
Illinois	42,029
Indiana	30,965
Michigan	23,944
Minnesota	61,480
Missouri	10,138
North Dakota	32,138
Nebraska	48,471
Ohio	17,445
South Dakota	48,547
Wisconsin	20,494

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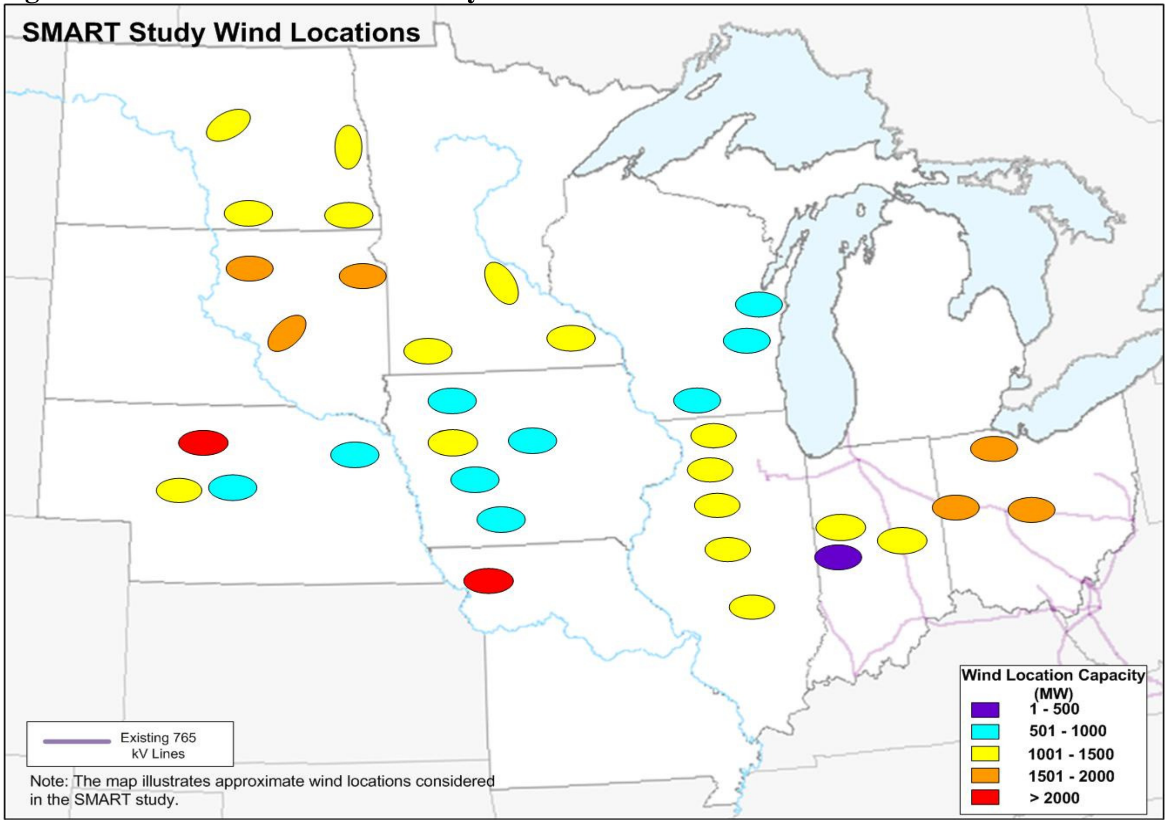
[2] The goal of EWITS was to evaluate the impact on the electric power system of increasing wind generation required to meet 20% and 30% of retail electric energy sales in the study region.

[3] The methods used to develop the wind sites and capacities by state are described on the NREL website (http://wind.nrel.gov/public/EWITS).

Table 3-4: Total Wind by State for Base Wind 2029

A	B	C	D	E	F	G	H	I	J
	Energy to meet ~80% RPS Requirement	**Existing Wind as of May 2009**	**Incremental wind to meet ~80% RPS Requirement**	**Incremental Wind Prorate of NREL by State**	**Energy (Import) / Export by State**	**% RPS Wind Generated In-State**	**Incremental Wind Prorate of NREL by State**	**Energy (Import) / Export by State**	**Total Wind by State Existing + Incremental**
State	MWh	MWh	(B-C) MWh	MWh	(E-D) MWh	%	MW	MW	MW
IA	9,015,631	10,109,338	(1,093,707)	12,055,001	13,148,708	100%	3,641	3,857	6,694
IL	34,086,968	4,441,320	29,645,648	16,370,614	(13,275,034)	61%	6,229	(3,894)	7,919
IN	21,791,519	2,946,645	18,844,874	7,238,053	(11,606,822)	47%	2,542	(3,404)	3,577
MI	21,766,944	342,402	21,424,541	21,424,541	0	100%	8,072	0	8,201
MN	18,684,256	5,739,683	12,944,572	12,944,572	0	100%	4,071	0	5,876
MO	17,034,255	958,221	16,076,034	8,562,158	(7,513,876)	56%	2,761	(2,204)	3,070
ND	2,371,073	2,674,130	(303,057)	14,176,611	14,479,667	100%	4,066	4,247	4,833
NE	5,625,797	540,133	5,085,664	17,801,633	12,715,968	100%	5,043	3,730	5,196
OH	25,169,839	18,641	25,151,198	12,575,599	(12,575,599)	50%	4,722	(3,689)	4,729
SD	2,111,696	1,019,244	1,092,452	13,873,332	12,780,880	100%	3,920	3,749	4,208
WI	14,739,279	1,500,588	13,238,691	5,084,796	(8,153,895)	45%	1,935	(2,392)	2,506
Total	172,397,256	30,290,346	142,106,911	142,106,911			47,002	0	56,809

Figure 3-1: SMARTransmission Study Wind Locations



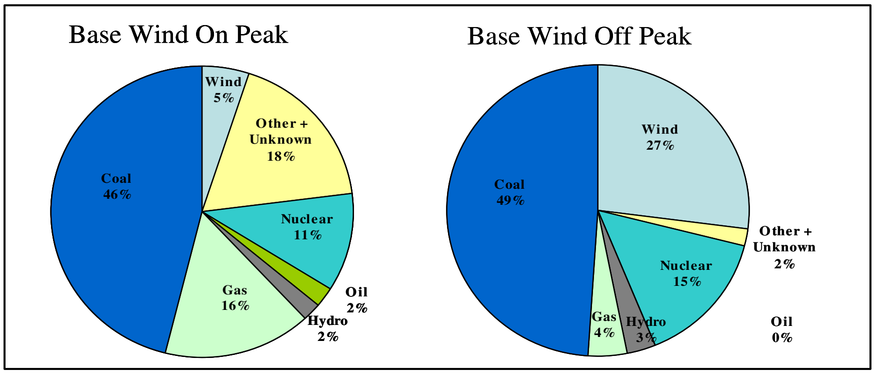
3.1.3 Energy Contribution of Wind Farms

Traditional reliability studies focus on summer peak hours since the load is generally at its highest during those times, and the transmission facilities are stressed. Wind generation often has limited availability during those hours. To account for the wind generation profile, this study assumes a wind contribution of 20% of the installed nameplate capacity for the summer peak case. Since wind farms generally produce more energy during off peak hours, (approximately 70% of summer peak), the study assumed a wind contribution of 90% during those hours. During periods of high wind generation and low consumer loads, the EHV overlay facilities are expected to be most heavily loaded, consistent with experience in real-time operations. For both on and off peak hours, reliability studies were conducted to ensure thermal loading and voltage limits would remain within acceptable levels.

3.1.4 Base Wind Case

The nameplate wind generation capacity required to meet the SMARTransmission RPS assumptions was 56.8 GW. Wind contribution in the off peak case (90% of 56.8 GW or approximately 51.1 GW) as compared to the on peak case (20% of 56.8 GW or approximately 11.4 GW) changes the pattern of the power flow across the study area and stresses the system in different locations. Generation resource allocations for the on and off peak base wind future are shown in **Figure 3-2.**

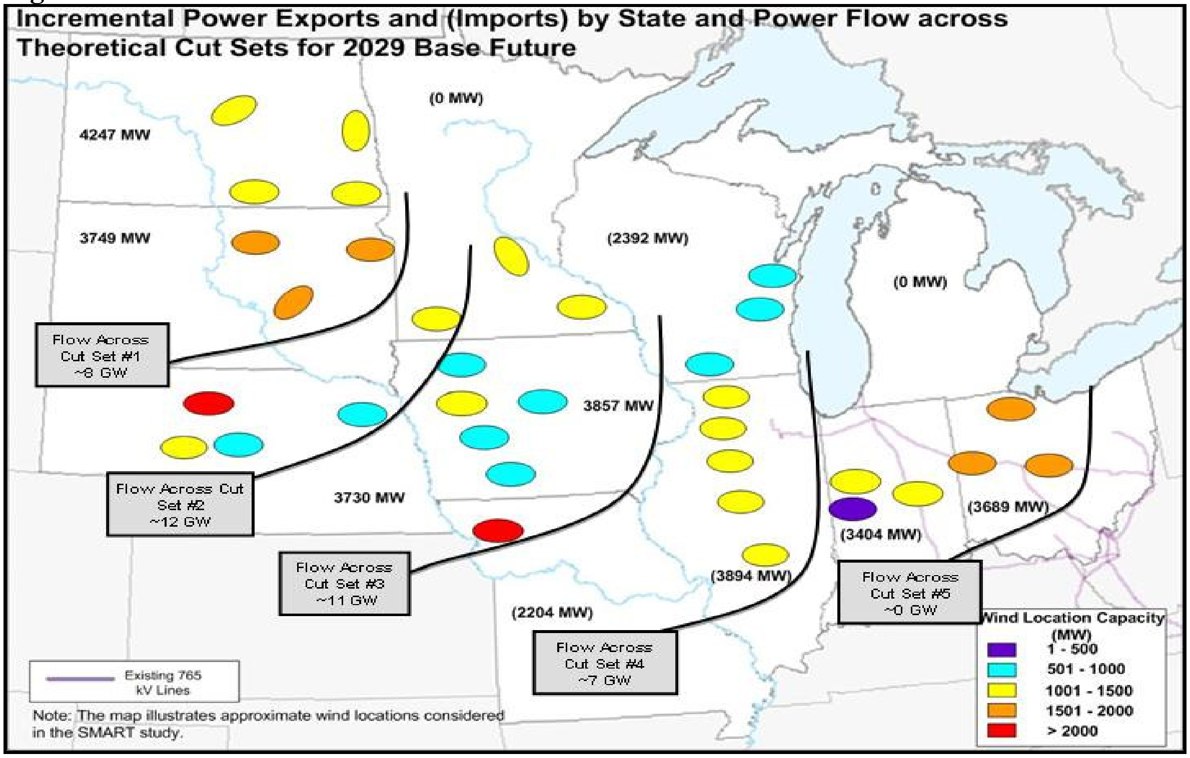
Figure 3-2: Base Wind On and Off Peak Resource Composition



3.1.5 Wind Generation Transfers

One of the key drivers of the SMARTransmission study is to support renewable energy development and facilitate the transportation of clean energy to consumers throughout the study area. As a result, it is important to understand the flow of wind power across the study area. The five theoretical cut sets shown in **Figure 3-3** were developed to illustrate the potential flows of wind power from those states that have wind generation potential in excess of that needed to meet their own renewable energy requirements. The initial eight conceptual EHV transmission overlay alternatives were designed by determining the transmission capacity needed to deliver power across each cut set. For example, to transport the eight gigawatts (GW) of power as shown in the first cut set, the transmission system would need to be designed to carry approximately eight GW from the first cut set to the second cut set. Power will flow on both the EHV overlay and the existing transmission system.

Figure 3-3: Theoretical Cut Sets for Power Flow



4 2029 Conceptual EHV Transmission Overlay Alternatives

During the first phase, the study group identified eight conceptual EHV transmission overlay alternatives, intended to facilitate the integration of 56.8 GW of nameplate wind generation within the study area. The alternatives were chosen based on their projected ability to meet the wind power transfer requirements shown in the cut sets in **Figure 3-3. Figure 4-1** through **Figure 4-8** show the conceptual EHV transmission overlays that were developed for 2029. Of these eight conceptual EHV transmission overlay alternatives, one was exclusively 345 kV, two were a combination of 345 kV and 765 kV, and five were exclusively 765 kV. When developing the eight conceptual EHV transmission overlay alternatives, the group considered all voltages including HVDC.

4.1 Reliability Analysis

Reliability analysis was performed on the eight conceptual EHV transmission overlay alternatives in order to identify and select the best performing alternatives for further evaluation. This analysis included the simulations of single contingencies[4] for transmission facilities within the study area that have voltages of 345 kV and above. The conceptual EHV transmission overlay alternatives were designed to meet single contingency criteria. The alternatives were evaluated per the planning criteria described in Appendix A (Section 14). Transmission facilities with voltages of 200 kV and above were monitored for thermal and voltage violations. A high level summary of their performance is provided with each figure.

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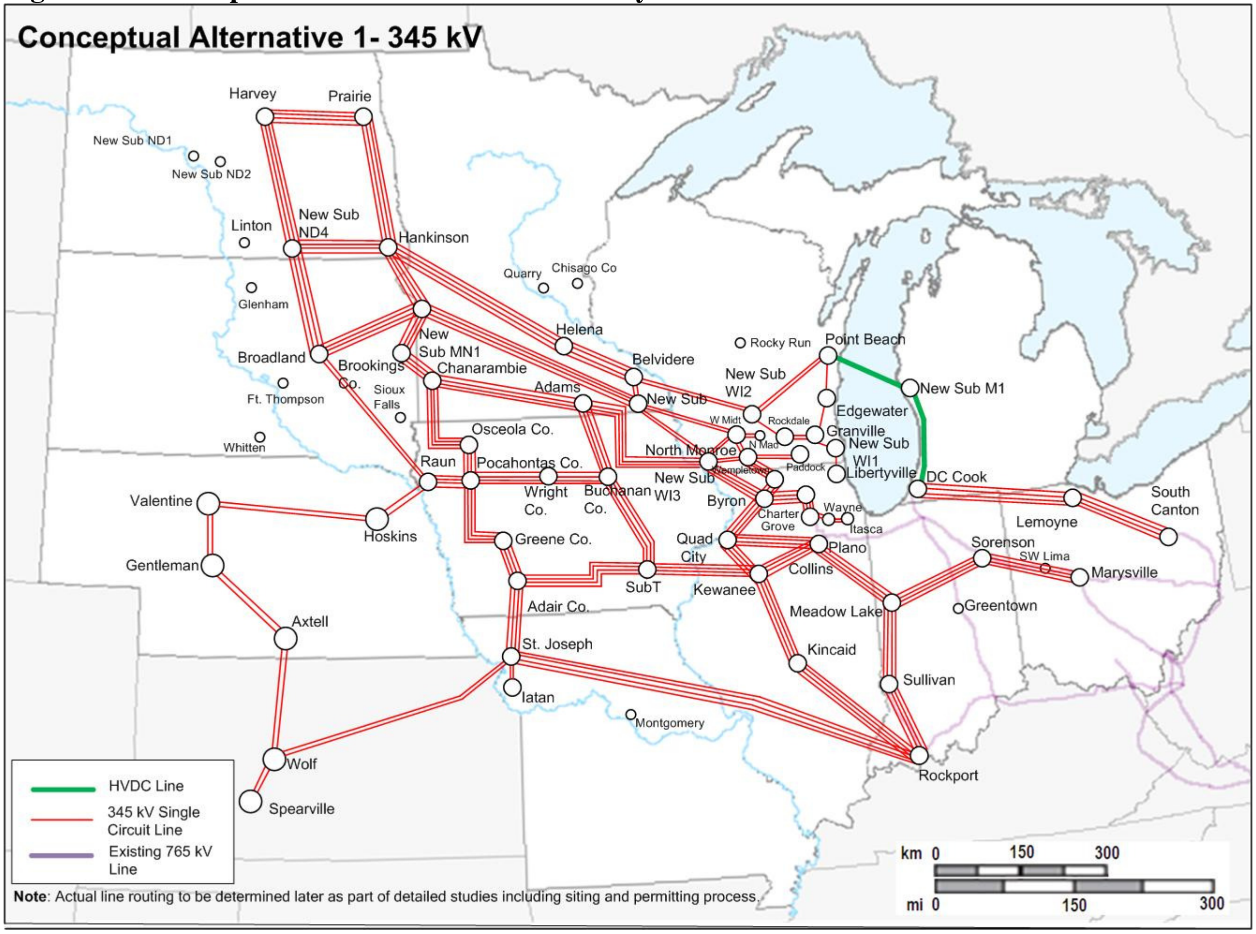
[4] A single contingency (N-1) simulation is used to evaluate the system conditions when one transmission facility is out of service.

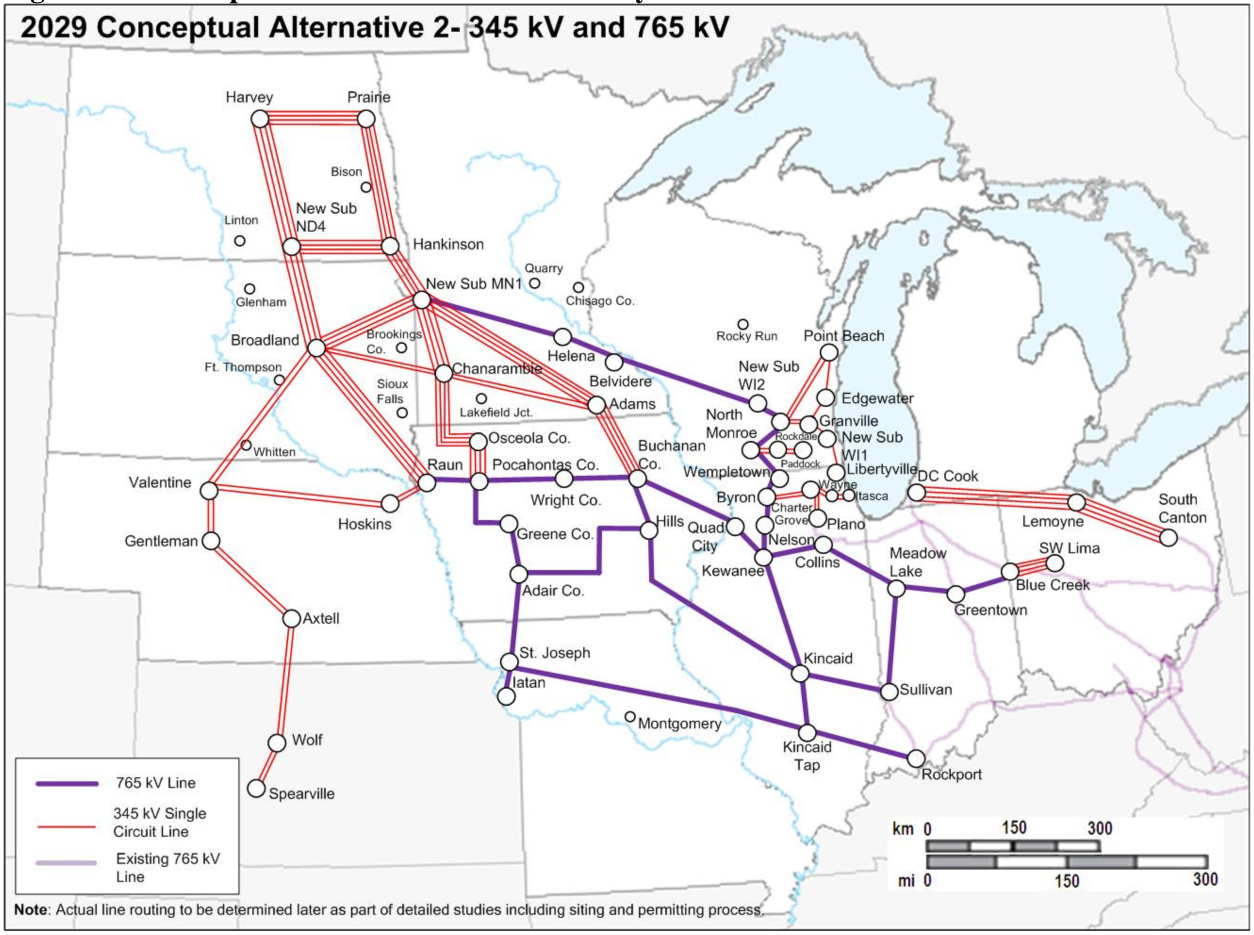
Figure 4-1: Conceptual EHV Transmission Overlay Alternative 1



Note: Actual line routing to be determined later as part of detailed studies including siting and permitting process.

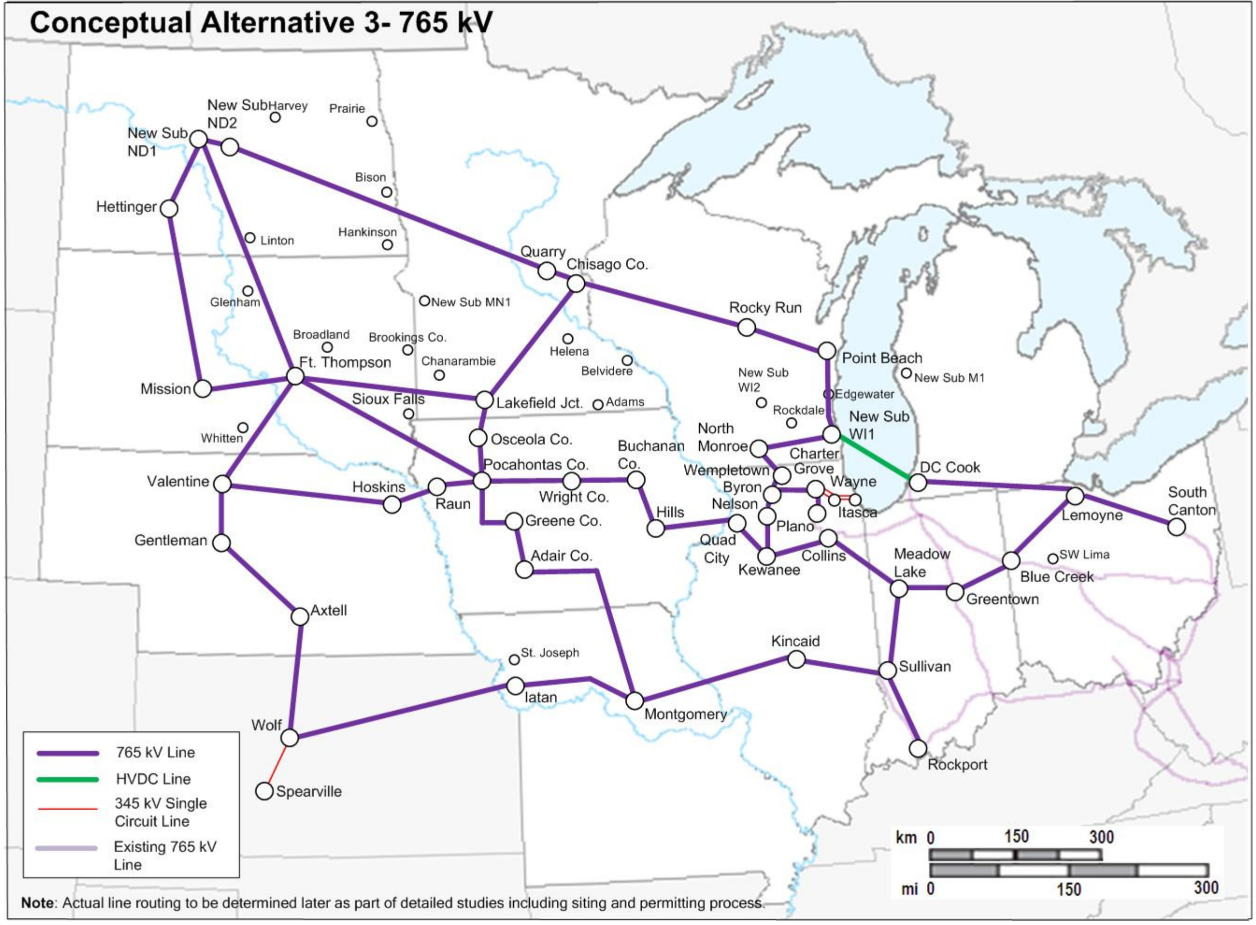
- Approximately 16,300 miles of 345 kV double circuit (~32,600 circuit miles)
- Second highest number of non-solving contingencies on EHV overlay for off peak case
- Long 345 kV lines from St Joseph to Rockport
- Five major paths west to east across cut set 4 shown in **Figure 3-3**

Figure 4-2: Conceptual EHV Transmission Overlay Alternative 2



- No non-solving contingencies on EHV overlay for off peak case
- Four major paths west to east across cut set 4 shown in **Figure 3-3**

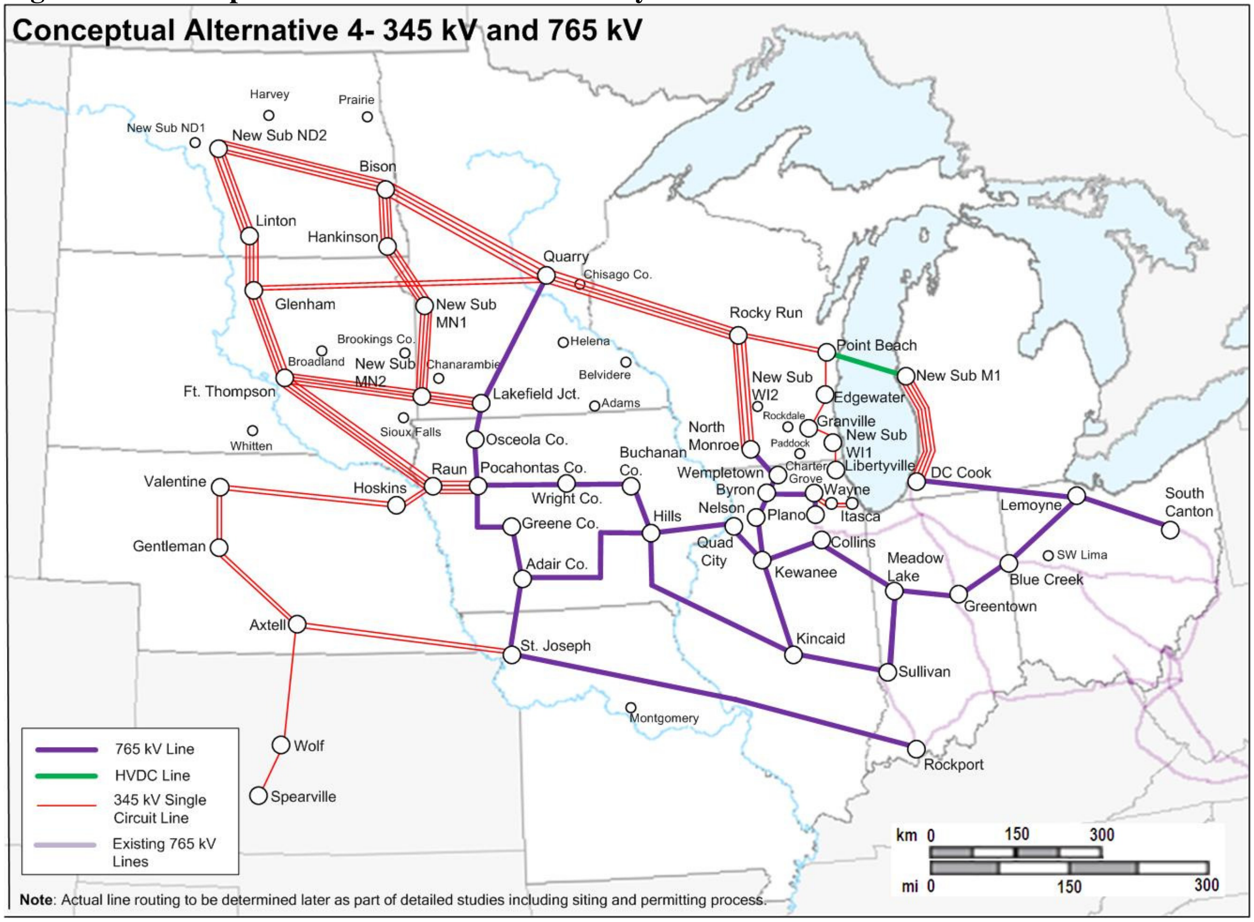
Figure 4-3: Conceptual EHV Transmission Overlay Alternative 3



Note: Actual line routing to be determined later as part of detailed studies including siting and permitting process.

- Long lines between areas which result in reliability issues
- Several non-solving contingencies
- Three major paths west to east across cut set 4 shown in **Figure 3-3.**

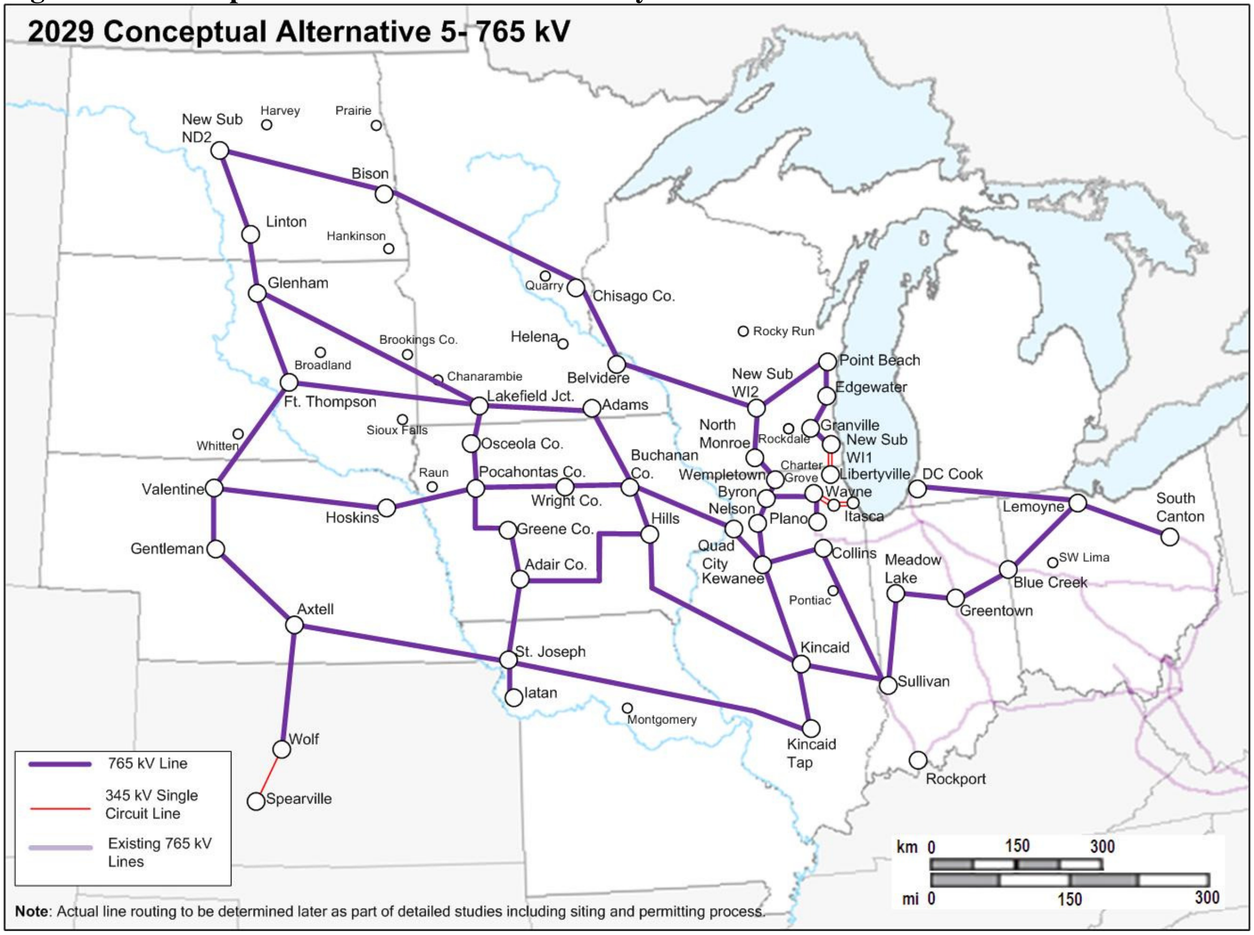
Figure 4-4: Conceptual EHV Transmission Overlay Alternative 4



Note: Actual line routing to be determined later as part of detailed studies including siting and permitting process.

- Nebraska transmission system not optimized. Alternative 2 addresses this issue.
- Iowa has contingency issues.
- Long 765 kV line from St Joseph to Rockport.

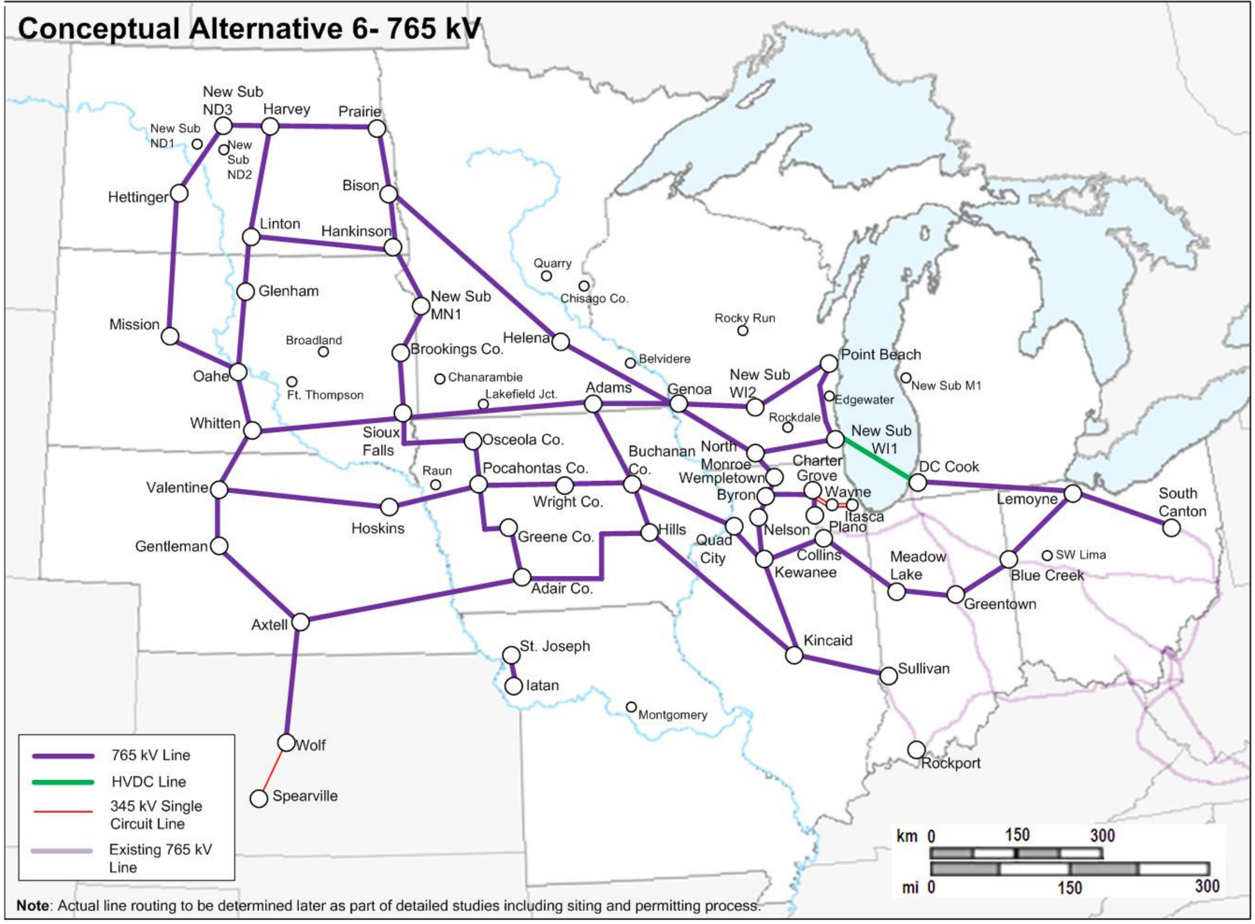
Figure 4-5: Conceptual EHV Transmission Overlay Alternative 5



Note: Actual line routing to be determined later as part of detailed studies including siting and permitting process.

- Large loop in the northwestern portion of the study area results in minor contingency issues.
- Contingency issues can be addressed through modifications.
- Four major paths west to east across cut set 4 shown in **Figure 3-3.**

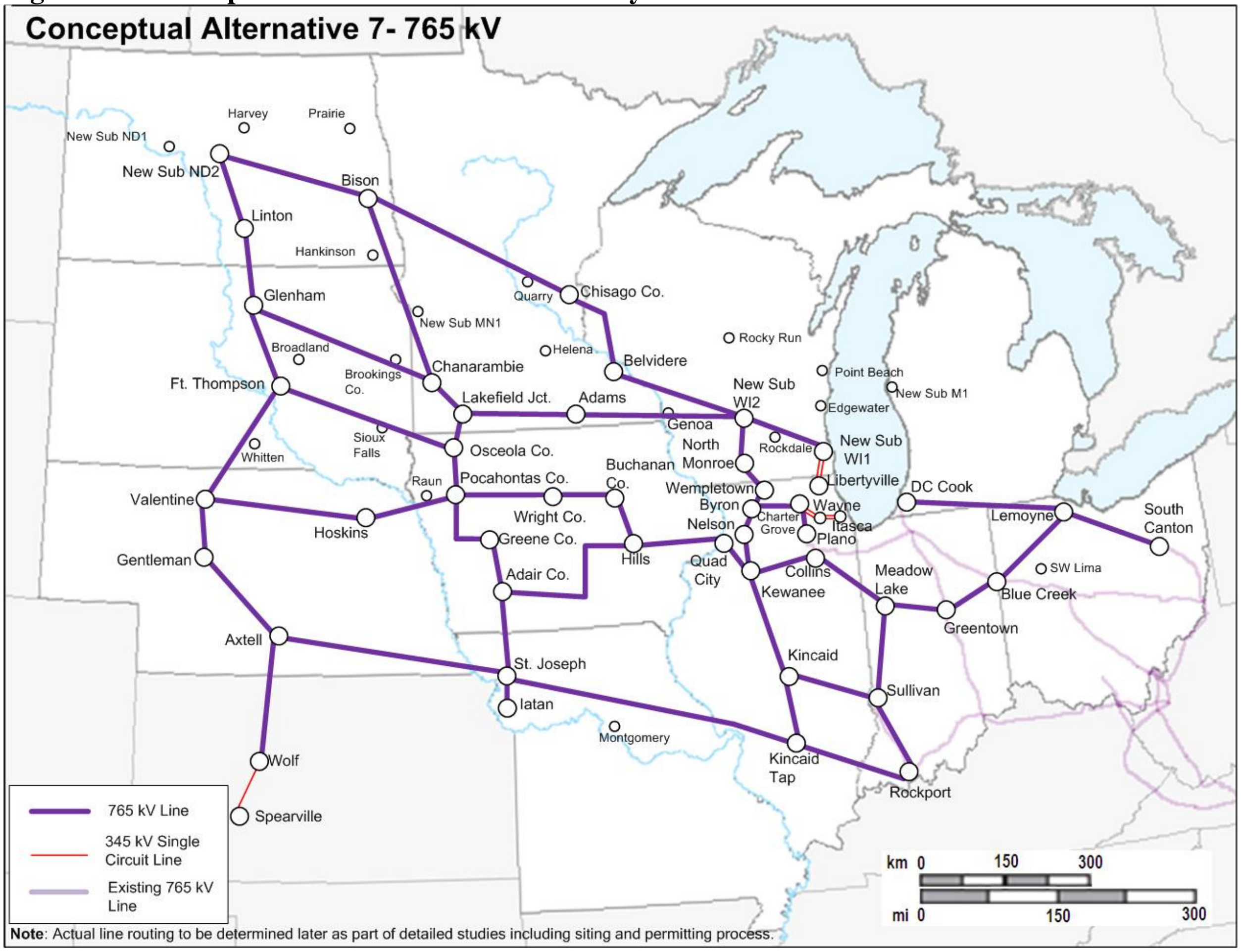
Figure 4-6: Conceptual EHV Transmission Overlay Alternative 6



Note: Actual line routing to be determined later as part of detailed studies including siting and permitting process.

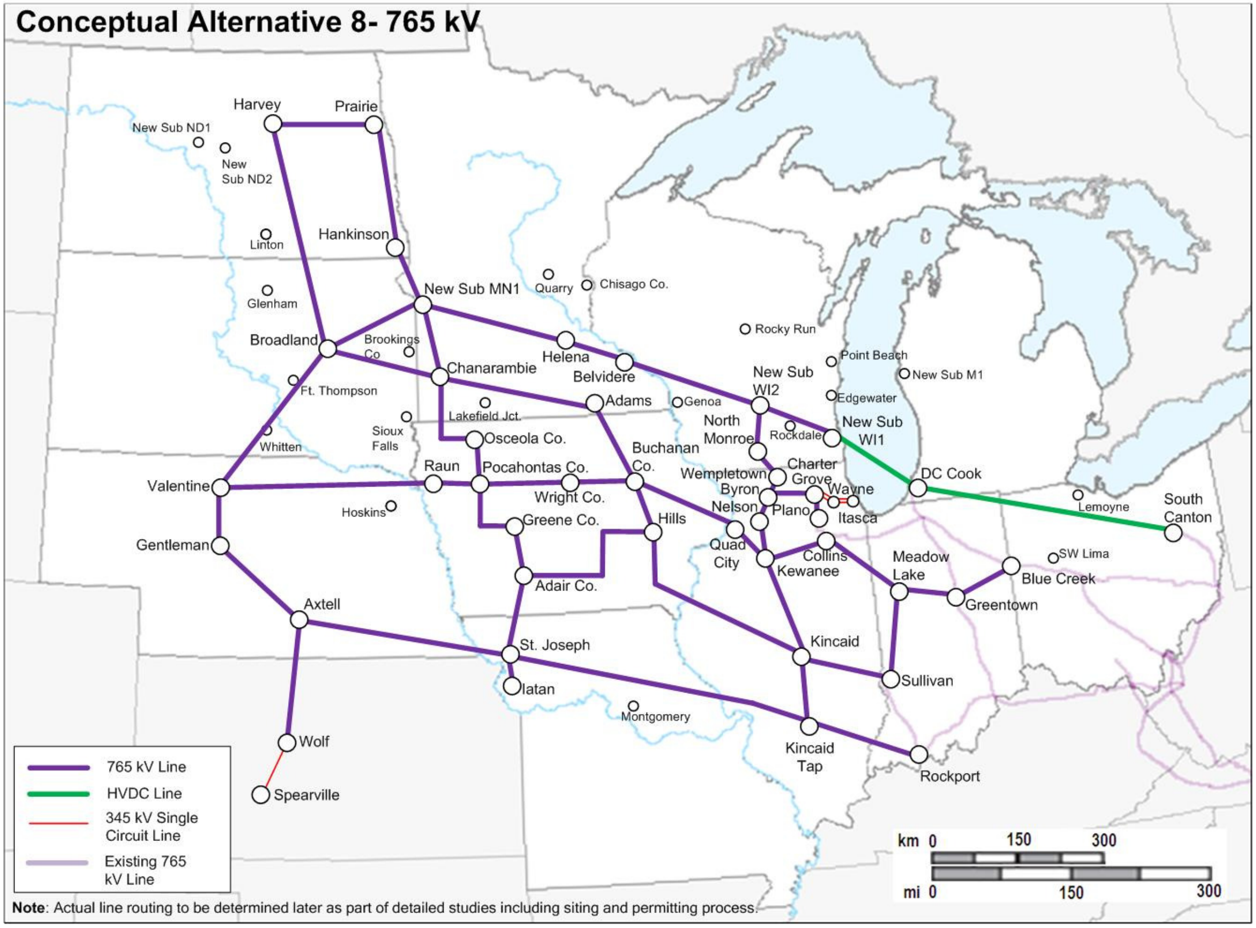
- Most non-solving contingencies on EHV overlays as compared to other alternatives.
- Substantial upgrades required to mitigate non-solving contingencies.

Figure 4-7: Conceptual EHV Transmission Overlay Alternative 7



- No non-solving contingencies on EHV overlay for off peak case.
- Four major paths west to east across cut set 4 shown in **Figure 3-3.**

Figure 4-8: Conceptual EHV Transmission Overlay Alternative 8



Note: Actual line routing to be determined later as part of detailed studies including siting and permitting process.

- Numerous non-solving contingencies on EHV overlays as compared to other alternatives.
- Location of non-solving contingencies will necessitate substantial upgrades to mitigate non-solving contingencies.
- Four major paths west to east across cut set 4 shown in **Figure 3-3.**

Table 4-1 provides a summary of the important features of each of the conceptual EHV transmission overlay alternatives.

Table 4-1: Summary of Conceptual EHV Transmission Overlay Alternatives

High Level Summary	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6	Alt 7	Alt 8
Single circuit 345 kV lines (number of lines)	225	96	8	92	12	8	6	8
Total 345 kV double circuit structure miles	16,271	7,156	339	7,734	350	339	339	339
Single circuit 765 kV lines (number of lines)	0	30	45	30	52	56	48	48
Total 765 kV circuit miles	0	3,829	6,917	4,037	7,887	8,253	7,264	6,707
Total construction miles	16,271	10,985	7,256	11,771	8,237	8,592	7,603	7,046
Total acreage	295,842	222,930	173,848	238,497	197,546	206,244	182,244	168,771
765/345 kV Transformers	1	18	28	16	25	32	33	30
345/230 kV Transformers	0	3	3	3	3	3	3	3
345 kV stations	150	64	5	61	8	5	5	5
765 kV stations	0	20	30	20	32	37	32	32
HVDC	yes	no	yes	yes	no	yes	no	Yes
Major river crossings	11	6	9	9	9	9	9	7

Single contingency simulations were completed for both on and off peak loading conditions. **Table 4-2** and **Table 4-3** show the number of N-1 contingencies on the existing EHV system as well as the EHV overlay elements that did not solve for each conceptual EHV transmission overlay alternative. A lower number of non-solving contingencies indicates a more robust transmission alternative. This means that the overlay alternative will require fewer modifications to alleviate performance issues. For example, at 56.8 GW of nameplate wind generation for the off peak case, Alternative 2 does not have any non-solving contingencies on the EHV overlay for single system contingency conditions, while Alternative 6 has 15 non-solving contingencies. This means that Alternative 2 can deliver the 56.8 GW of wind generation under single contingency conditions while Alternative 6 will need modifications, some of which may constitute significant upgrades to deliver the generation under single contingencies. Any number other than zero in the tables indicates that the alternative will require modifications to eliminate the violations.

Table 4-2: Summary Results Off peak

Non-Solving Contingencies	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6	Alt 7	Alt 8
EHV Overlay	14	0	4	4	2	15	0	9
Existing EHV Facilities	9	1	2	11	2	1	3	2

Table 4-3: Summary Results On peak

Non-Solving Contingencies	**Alt 1**	**Alt 2**	**Alt 3**	**Alt 4**	**Alt 5**	**Alt 6**	**Alt 7**	**Alt 8**
EHV Overlay	0	0	2	0	2	3	1	1
Existing EHV Facilities	8	11	8	8	7	9	9	24

4.2 Cost Analysis

Table 4-4 shows transmission station and line costs that were developed using common estimating philosophies. The costs were developed using up-to-date standards and design criteria, material costs from similar projects, and optimized line and station designs for both flat and mountainous terrain. The costs were also designed to include environmental and siting requirements.

Table 4-4: Cost Estimates for Conceptual EHV Transmission Overlay Alternatives

Element	**$M**
Transmission Lines (includes right-of-way costs)	
Single circuit 345 kV (USD / mile)	1.50
Double circuit 345 kV (USD / mile)	1.97
Single circuit 765 kV (USD / mile)	2.71
Transformers	
345/230 kV, 500 MVA (USD / unit)	6.5
765/345 kV, 1000 MVA (USD / unit)	12.0
765/345 kV, 2250 MVA (USD / unit)	21.0
Network Stations (does not include land costs)	
345 kV (USD / station)	11.8
765 kV (USD / station)	25.1
Major River crossings	7.0
HVDC Undersea Cable (USD / mile)	9.0
HVDC Overhead (USD / mile)	5.0

Table 4-5 applies the costs in **Table 4-4** to the components in **Table 4-1** to calculate the estimated cost of each conceptual EHV transmission overlay alternative.

Table 4-5: Cost Summary for Conceptual EHV Transmission Overlay Alternatives

Estimated Costs ($ M)	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6	Alt 7	Alt 8
345 kV Double Circuit Lines	$32,054	$14,098	$668	$15,237	$689	$668	$668	$668
765 kV Lines	$0	$10,375	$18,745	$10,941	$21,373	$22,366	$19,687	$18,177
Total Transmission Lines	$32,054	$24,474	$19,413	$26,178	$22,061	$23,034	$20,355	$18,845
Transformer Costs								
765/345 kV Transformers	$21	$378	$588	$336	$525	$672	$693	$630
345/230 kV Transformers	$0	$17	$17	$17	$17	$17	$17	$17
Total Transformation	$21	$395	$605	$353	$542	$689	$710	$647
345 kV Network Substation/Station	$1,770	$755	$59	$720	$94	$59	$59	$59
765 kV Network Substation/Station	$0	$502	$753	$502	$803	$929	$803	$803
Total Costs Substation/Station	$1,770	$1,257	$812	$1,222	$898	$988	$862	$862
HVDC	$1,810	-	$1,080	$810	-	$1,080	-	$2,480
River Crossings	$77	$42	$63	$63	$63	$63	$63	$49
Preliminary Estimated Costs	$35,732	$26,168	$21,973	$28,625	$23,564	$25,854	$21,990	$22,883

4.3 Alternative Selection Process

Based on the cost and reliability analysis, five of the eight conceptual EHV transmission overlay alternatives were eliminated from further study. One combination 345 kV/765 kV alternative (Alternative 4) was eliminated because it had the second highest cost estimate and a significantly higher number of reliability issues as compared to some of the other alternatives. Three 765 kV-only options (Alternatives 3, 6, and 8) were eliminated because they had a significant number of reliability issues as compared to some of the other alternatives. Mitigating the issues would have required substantial upgrades and added to the cost of those alternatives.

Based on the cut sets, the 345 kV alternative (Alternative 1) provided sufficient power transfer capability to move 56.8 GW of wind. This alternative was more expensive and was not as reliable as the other options during single contingency simulations so it was not chosen for further consideration at the 56.8 GW level. This option was further studied to determine its performance at a lower level of wind (36.1 GW nameplate) which is somewhat more reflective of current state renewable energy standards, rather than the 56.8 GW of wind that reflects 80% of the energy required to meet a base level of 20% federal Renewable Portfolio standard in the study area. Additional information regarding the Low Wind scenario can be found in Section 16.2 of the Appendix.

Alternatives 2, 5 and 7 were selected for further evaluation.

4.4 Reliability Performance Metrics

The SMARTransmission team developed a series of metrics to rank the performance of Alternatives 2, 5, and 7. **Table 4-6** describes these metrics. The EHV overlay was designed to support the integration of 56.8 GW of wind power, while ensuring there were no thermal or voltage violations under normal (with all facilities in service) and single contingency conditions. The 56.8 GW of wind generation changes the power flow patterns, resulting in new reliability issues on the existing system facilities. Violations on the existing system are more localized and are highly dependent upon the location and magnitude of the wind generation facilities. When the locations and magnitudes of future wind farms are determined, the RTOs will perform generation interconnection studies to resolve potential system issues associated with their development. The study used the violations on the existing system for alternative comparison purposes only.

Table 4-6: Reliability Performance Metrics

Simulations	Description
Overlay voltage violations : All facilities in-service	EHV overlay bus voltages that operate outside the system voltage limits (Table A-5) with all transmission facilities in service.
Overlay thermal violations: All facilities in-service	EHV overlay facilities that exceed their applicable thermal ratings with all transmission facilities in service.
Non Solving Contingencies: EHV Overlay	Single contingencies of EHV Overlay facilities that result in non-convergent solutions[5].
Overlay thermal violations: Overlay N-1	EHV overlay facilities that exceed the applicable thermal ratings following the loss of a single EHV overlay facility.
Overlay voltage violations: Overlay N-1	EHV overlay bus voltages that operate outside the system voltage limits (Table A-5) following the loss of a single EHV overlay facility.
Existing System Thermal Violations: All facilities in-service	Existing transmission facilities that exceed their applicable thermal ratings with all transmission facilities in service.
Non-solving contingencies: Existing System	Single contingencies of existing transmission facilities that result in non-convergent solutions.
Existing System thermal violations: Overlay N-1	Existing transmission facilities that exceed their applicable thermal ratings following the loss of a single EHV Overlay facility.
Existing System thermal violations: Existing System N-1	Existing transmission facilities that exceed their applicable thermal ratings following the loss of other existing transmission facilities taken one at a time.

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[5] The sum of all power flows at any particular node must be zero or reasonably close to zero. A convergent solution is achieved by a mathematical algorithm which iterates with the objective of reducing the sum of power flows to some acceptable small value called mismatch tolerance. A non-convergent solution occurs when mismatch tolerance is not met.

4.5 2029 Transmission Alternative 1 (345 kV) Performance Evaluation

Quanta analyzed the performance of the 345 kV option at lower wind levels. The performance of the 345 kV alternative is shown in **Table 4-7.** Sensitivity analysis shows that the 345 kV alternative would be a feasible alternative to support 36.1 GW of wind generation, although the cost would be significantly higher than the alternatives selected for further analysis.

Table 4-7: Performance results of Conceptual Alternative 1 at 36.1 GW of Wind

Row	Simulations	Violations
1	Overlay voltage violations: All facilities in-service	0
2	Overlay thermal violations: All facilities in-service	0
3	Non-solving Overlay N-1	0
4	Overlay thermal violations: Overlay N-1	0
5	Overlay voltage violations: Overlay N-1	0
6	Existing System Thermal violations: All facilities in-service	3
7	Non-solving Existing System N-1	1
8	Existing System thermal violations: Overlay N-1	0
9	Existing System thermal violations: Existing System N-1	14

4.6 Revised Alternatives

Alternatives 2, 5, and 7 were optimized for reliability performance. For example, the analysis of conceptual Alternative 5 shows two non-solving contingencies on the conceptual EHV Overlay. These were addressed by adding a 765 kV transmission line from Bison (ND) to Helena (MN) to Belvidere (MN). Lightly loaded facilities were removed as long as reliability was not negatively impacted. For example, St. Joseph (MO) – Rockport (IN) 765 kV transmission line was eliminated from the alternatives. In addition, an HVDC line across Lake Michigan was added. The HVDC line provides another reliable east-west tie and alleviates constraints associated with the rapidly developing wind generation in Eastern Wisconsin. Changes to optimize Alternative 7 made it similar to Alternative 5. As a result, Alternative 7 was removed from further evaluation.

4.6.1 High Voltage Direct Current (HVDC)

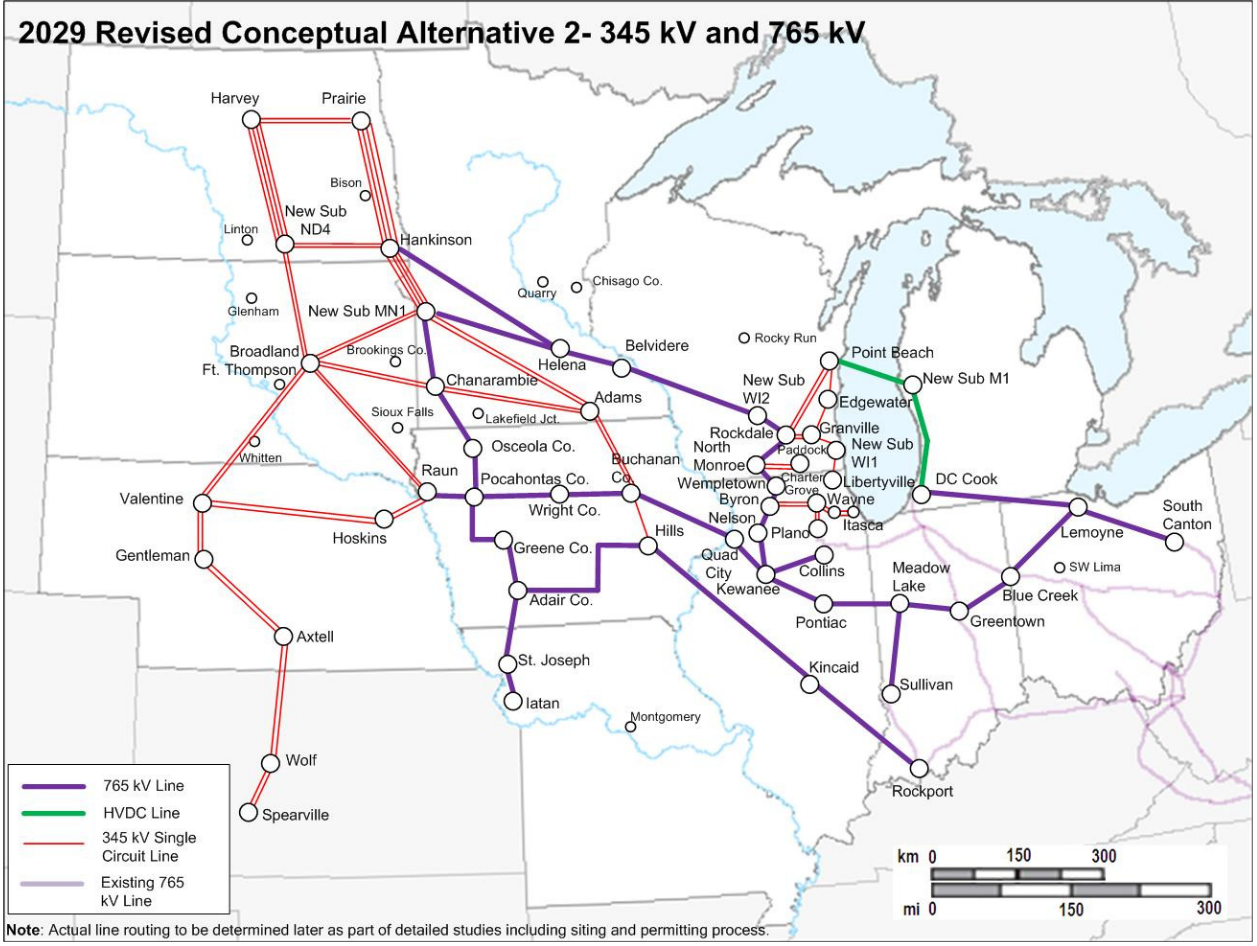
HVDC additions to the conceptual alternatives were based on finding natural applications within the study area. Some of the natural applications for HVDC include linking two asynchronous grids and moving power over long distances, including underground and underwater.

Applications were determined by the potential locations of wind generation collection systems, EHV overlay connections to the local transmission systems, and renewable energy costs and requirements. Underwater cables across Lake Michigan (approximately 91 miles of ±400 kV, 1200 MW) and a long-distance transmission line between Adair County and Sullivan Stations (approximately 385 miles of ±400 kV, 2000 MW) were incorporated into the study.

4.6.2 Maps of Revised Conceptual EHV Transmission Overlay Alternatives

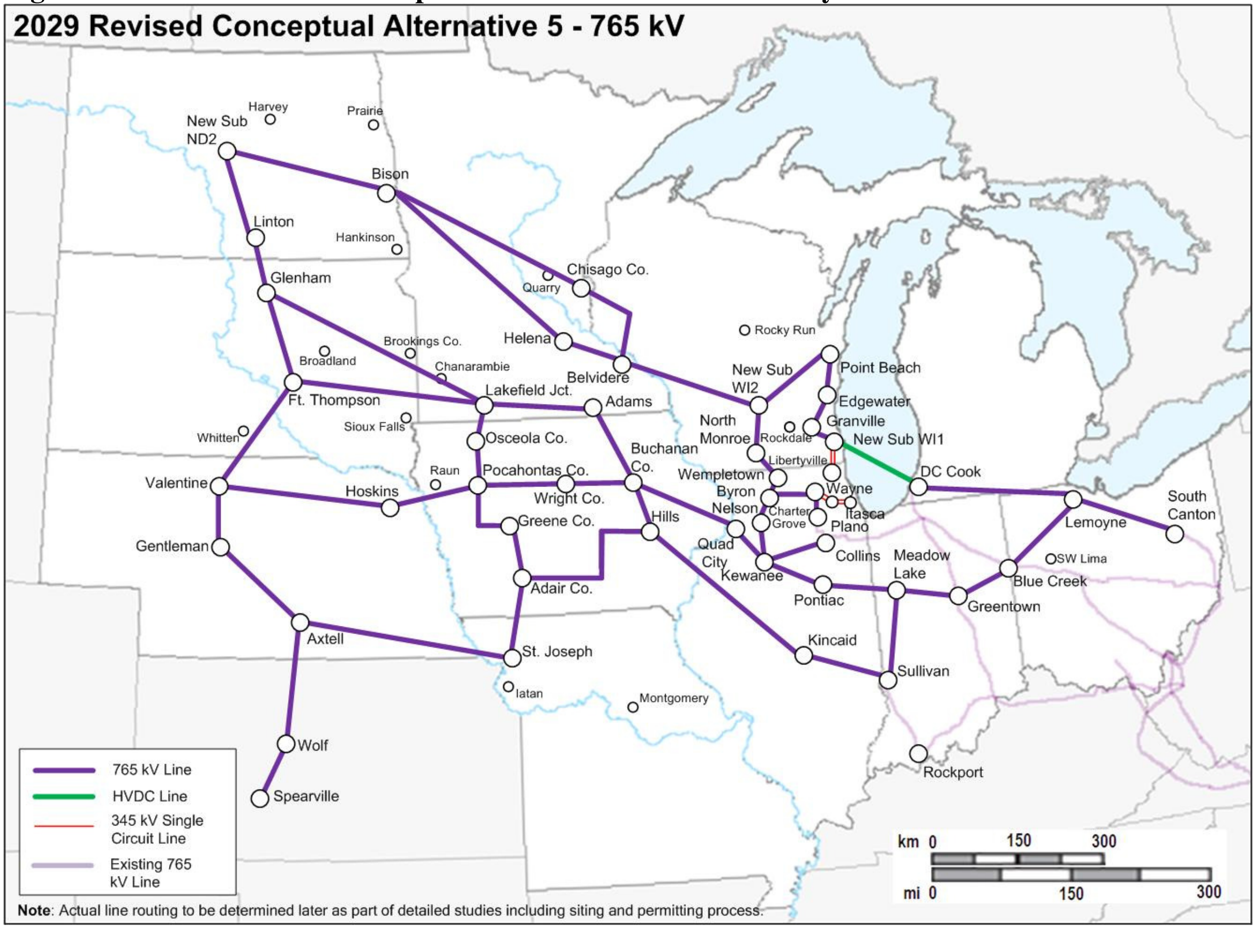
Alternative 5 was modified to include an HVDC line from Adair County to Sullivan Station and selected for further study as Alternative 5A. The three alternatives were optimized to eliminate the lightly loaded lines and are shown in **Figures 4-9** through **4-11**.

Figure 4-9: 2029 Revised Conceptual EHV Transmission Overlay Alternative 2



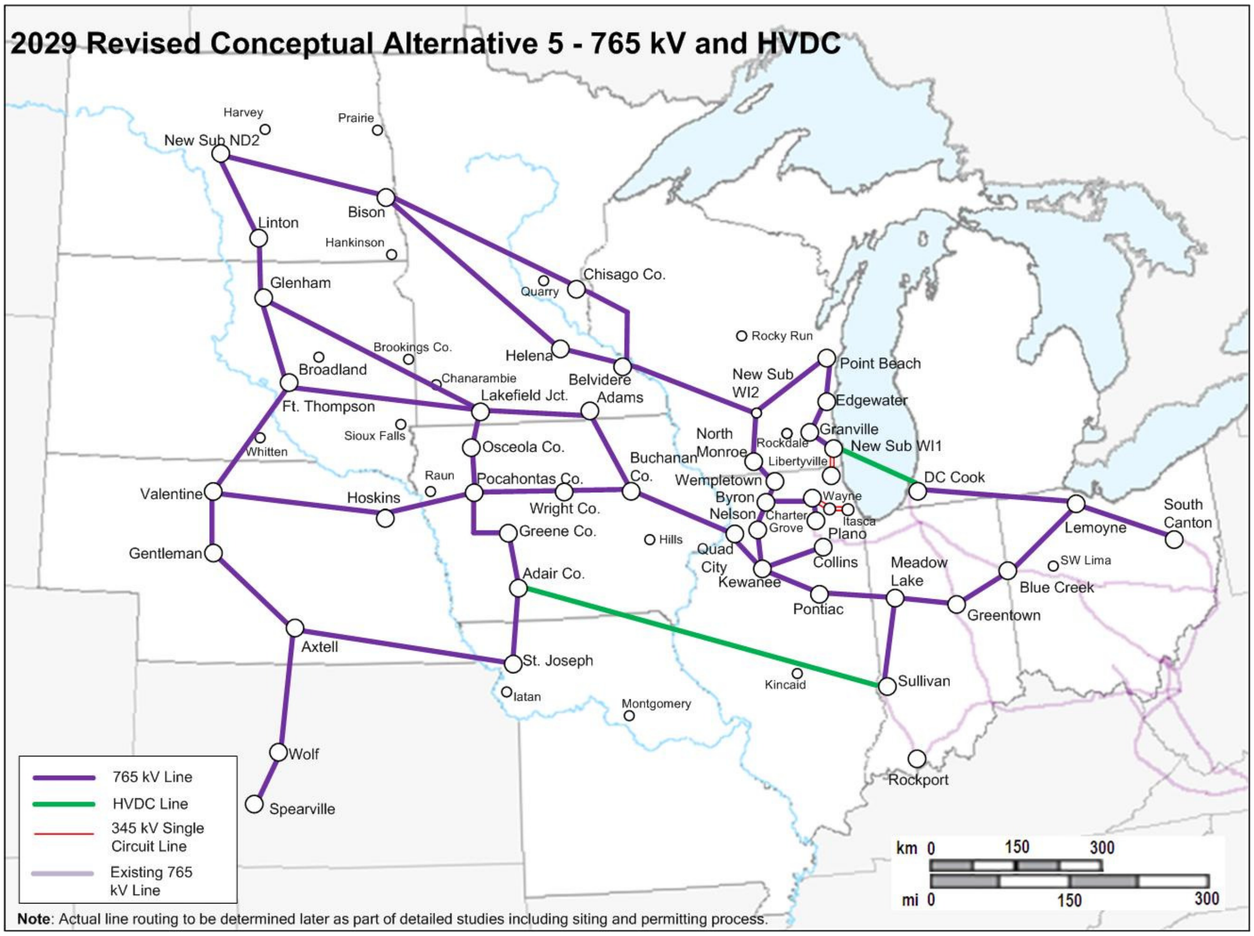
Note: Actual line routing to be determined later as part of detailed studies including siting and permitting process.

Figure 4-10: 2029 Revised Conceptual EHV Transmission Overlay Alternative 5



Note: Actual line routing to be determined later as part of detailed studies including siting and permitting process.

Figure 4-11: 2029 Revised Conceptual EHV Transmission Overlay Alternative 5A - Includes HVDC



4.7 Analysis of Revised Alternatives

Reliability analysis was performed on the revised alternatives. Single contingency analysis was performed per the planning criteria described in Appendix A. Double contingency[6] analysis was performed to test the strength of the overlays under higher stress conditions and was used to compare the alternatives. Transmission facilities with voltages of 200 kV and above were monitored for thermal and voltage violations.

The single contingency analysis confirmed that the modifications made to the revised alternatives alleviated the violations in the Alternative 5 overlay as shown in **Table 4-2**. The revised overlay alternatives do not show any significant steady state thermal or voltage constraints for the base wind on and off peak cases. Rows 1 through 5 in **Table 4-8** reflect the revised EHV overlay violations that result from outages on the existing or revised EHV overlays. Voltage violations in Row 5 for Alternative 2 in the off peak case and Alternatives 2, 5, and 5A in the on peak case are not of major concern because those violations can be eliminated with capacitors or reactors. Rows 6 through 9 reflect existing facility

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[6] A double contingency (N-2) simulation is used to evaluate the system conditions when two transmission facilities are out of service at the same time.

violations that result from outages on the existing or revised EHV overlays. These violations are shown for completeness and are generally a function of load growth or wind resource locations.

Table 4-8: 2029 Base Wind Results for On and Off Peak Cases

		Off Peak			On Peak		
Row	**Number of Violations**	**Alt 2**	**Alt 5**	**Alt 5A**	**Alt 2**	**Alt 5**	**Alt 5A**
1	Overlay voltage violations: All facilities in-service	0	0	0	0	0	0
2	Overlay thermal violations: All facilities in-service	0	0	0	0	0	0
3	Non-solving Overlay N-1	0	0	0	0	0	0
4	Overlay thermal violations: Overlay N-1	0	0	0	0	0	0
5	Overlay voltage violations: Overlay N-1	1	0	0	2	1	1
6	Existing System Thermal violations: All facilities in-service	7	8	8	10	12	13
7	Non-solving Existing System N-1	4	3	3	12	12	12
8	Existing System thermal violations: Overlay N-1	5	21	23	3	6	4
9	Existing System thermal violations: Existing System N-1	54	56	56	106	113	85

The above analysis shows that Alternatives 2, 5, and 5A could support 56.8 GW of nameplate wind generation. Mitigations for violations on the existing transmission system are expected to be recommended during the annual RTO and local utility planning studies.

4.7.1 N-1-1 Analysis

Double contingency (N-2) analysis was performed on the revised alternatives to test their robustness. The sponsor group chose off peak models to perform the analysis since the off peak periods are characterized by high wind generation, low consumer loads, and heavily loaded EHV facilities. Double contingencies were simulated on the EHV Overlay elements and existing EHV facilities critical to the study. Consistent with NERC Planning Criteria, the N-2 contingencies were simulated using N-1-1 contingency[7] analysis on the revised EHV Overlay. Some of these N-1-1 contingencies resulted in non-convergent solutions. For example, approximately 1.2 GW of generation was curtailed in South Dakota for the Hankinson (ND) to Helena (ND) and New Sub MN1 (MN) to Helena (MN) 765 kV line outages to obtain a convergent solution in Alternative 2. Similarly, approximately 2.5 GW of generation was re-dispatched in North and South Dakota for the Bison (ND) to Helena (MN) and Bison (ND) to Chisago County (MN) 765 kV line outages in Alternative 5 and 5A. The reliability issues occurring on the existing system are expected to be addressed by generation re-dispatch and should be further evaluated in annual RTO or local utility planning studies.

4.8 Futures Analysis

Transmission Alternatives 2, 5, and 5A were designed to meet performance criteria under base wind assumptions. In addition to the 2029 base cases, two additional generation future cases (High Gas and Low Carbon) were created for analysis. Due to uncertainties associated with economic and political conditions, long range transmission plans should be based on a range of assumed scenarios or Futures. The study evaluated the transmission alternatives under the High Gas and Low Carbon Futures to assess the robustness of each alternative and compare their performances.

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[7] N-1-1 is a double contingency that allows for system adjustments after the first contingency and before the second. System adjustments include but are not limited to generation re-dispatch and load curtailment.

4.8.1 High Gas Future

The High Gas Future assumes that generation from gas facilities will increase faster than that from other conventional facilities. As compared to the base case, this future assumes that gas generation will increase from 40.0 GW to 51.7 GW. Incremental gas generation was added based on previous studies, gas line locations, and RTO queues. Coal units were reduced proportionally throughout the study area. The results of the N-1 contingency analysis for the 2029 High Gas Future are shown in **Table 4-9** for both the on and off peak base cases. This analysis indicates that with the exception of some minor deficiencies, the alternatives will perform well under the High Gas Future scenario.

Table 4-9: High Gas Results for On and Off Peak Cases

	2029 High Gas Future	**Off Peak**			**On Peak**		
Row	**Simulation**	**Alt 2**	**Alt 5**	**Alt 5A**	**Alt 2**	**Alt 5**	**Alt 5A**
1	Overlay voltage violations: All facilities in-service	0	0	0	0	0	0
2	Overlay thermal violations: All facilities in-service	0	0	0	0	0	0
3	Overlay unsolvable: Overlay N-1	0	0	0	0	0	0
4	Overlay thermal violations: Overlay N-1	0	0	2	0	0	0
5	Overlay voltage violations: Overlay N-1	1	0	0	2	2	2
6	Existing System Thermal violations: All facilities in-service	4	4	4	11	11	11
7	Existing System unsolvable: All N-1	5	3	3	11	13	13
8	Existing System thermal violations: Overlay N-1	7	13	17	2	3	6
9	Existing System thermal violations: Existing System N-1	74	58	41	84	89	111

4.8.2 Low Carbon Future

The Low Carbon Future is based on the premise of decreasing carbon emitting generation resources and increasing hydro, nuclear, and wind generation. The scenario assumes that 29 coal units, totaling approximately 2 GW, were retired. Coal generation was reduced by another 9 GW by lowering the output of remaining units. Additional information can be found in Section 1.3 of Appendix B.

The results of the N-1 contingency analysis for the 2029 Low Carbon Future is shown in **Table 4-10**. This analysis indicates that with the exception of some voltage deficiencies, the alternatives will perform well under the Low Carbon Future scenario. The actual locations of coal plant retirements as well as the location and size of new generation resources should be monitored as they could have a significant impact on the results of the Low Carbon Future.

Table 4-10: Low Carbon Results for On and Off Peak Cases

		Off Peak			On Peak		
Row	**Simulation**	**Alt 2**	**Alt 5**	**Alt 5A**	**Alt 2**	**Alt 5**	**Alt 5A**
1	Overlay voltage violations: All facilities in-service	0	0	0	0	0	0
2	Overlay thermal violations: All facilities in-service	0	0	0	0	0	0
3	Overlay unsolvable: Overlay N-1	3	4	6	0	0	1
4	Overlay thermal violations: Overlay N-1	0	0	0	0	0	0
5	Overlay voltage violations: Overlay N-1	5	1	2	3	2	2
6	Existing System Thermal violations: All facilities in-service	2	6	6	13	15	16
7	Existing System unsolvable: All N-1	2	3	0	10	9	9
8	Existing System thermal violations: Overlay N-1	24	16	13	6	4	4
9	Existing System thermal violations: Existing System N-1	90	44	46	148	130	129

4.9 Sensitivity Analysis

Three sensitivities were run to determine how changes to a key assumption in the 2029 base cases impacts the performance of the transmission alternatives. The sensitivities studied were a High Wind generation case, a Low Wind generation case and an SPP Import case. The sensitivity cases were developed from the off peak future cases. The High Wind generation sensitivity was designed to address higher than expected energy usage associated with economic growth during the 20-year period. For this sensitivity, renewable requirements were based on 2% energy growth as opposed to the 1% assumed in the base case. This results in a High Wind nameplate generation of 70.5 GW. See **Table A-9 and Table A-10** in Appendix A for additional information. Conversely, the Low Wind generation sensitivity was designed to address uncertainties around renewable energy polices and take into account lower than anticipated energy growth during the 20-year period. Based on existing RPS requirements and energy growth of 0.3% as opposed to 1% in the base case, the Low Wind nameplate generation was calculated to be 36.1 GW. See **Table A-11 and Table A-12** in Appendix A for additional information. Given the significant wind activity in SPP, Quanta performed a sensitivity to provide insight into the contribution of the SPP wind to the eastern market. For this sensitivity, approximately 6 GW of wind generation was imported from the SPP region. Wind generation locations were based on results from the SPP Overlay Study[8] completed by Quanta in 2008. These sensitivities were run for the off peak future cases because they are characterized by high wind generation, low consumer loads, and heavily loaded EHV facilities.

Additionally, higher and lower than forecasted load growth sensitivities were used to assess a range of possible future load conditions. These sensitivities were applied to on peak future cases due to higher demand levels as compared to off peak cases. For the high load sensitivity, the 2029 base case demand levels were increased by 1% resulting in a load level of 168 GW. **Table 4-11** shows that Alternatives 5 and 5 A perform adequately, and Alternative 2 shows stress under the high load sensitivity. For the low load sensitivity, the 2029 base case demand levels were decreased by 5%[9], resulting in load levels of 158.2 GW. An analysis of this sensitivity was performed on the Base Wind Future case to gain insight

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[9] In general, MISO considers a 5% increase and decrease in load levels to account for uncertainties in load projections.

into the lightly loaded transmission lines that might not be required under the Low Load scenario. Further analysis will be required to determine if the overlay performs adequately under contingency conditions with the lightly loaded lines removed.

4.9.1 Base Case Future Sensitivity Analysis

The High Wind and SPP Import sensitivity results in Table 4-11 show several unsolved contingencies (Row 3) in all the alternatives. These results are indicative of a transmission network that is stressed and is exceeding its capability. The locations and magnitude of new wind farms as well as load growth should be monitored as they could have a significant impact on the results. The Alternatives perform adequately under the Low Wind sensitivity.

Table 4-11: Base Wind Future Results – Generation Sensitivities

		High Wind			**Imports from SPP**			**Low Wind**		
Row	**Base Case Wind**	**Alt 2**	**Alt 5**	**Alt 5A**	**Alt 2**	**Alt 5**	**Alt 5A**	**Alt 2**	**Alt 5**	**Alt 5A**
1	Overlay voltage violations: All facilities in-service	0	0	0	0	0	2	0	0	0
2	Overlay thermal violations: All facilities in-service	0	0	0	0	0	0	0	0	0
3	Overlay unsolvable: Overlay N-1	14	7	12	13	3	4	0	0	0
4	Overlay thermal violations: Overlay N-1	4	3	1	0	0	0	0	0	0
5	Overlay voltage violations: Overlay N-1	6	8	3	2	1	1	8	11	11
6	Existing System Thermal violations: All facilities in-service	18	18	20	11	9	11	2	2	2
7	Existing System unsolvable: All N-1	8	3	3	22	5	2	4	4	3
8	Existing System thermal violations: Overlay N-1	11	93	68	4	39	46	1	3	3
9	Existing System thermal violations: Existing System N-1	58	244	195	95	94	98	23	12	13

Table 4-12: Base Wind Future Results – Load Sensitivities

		High Load			Low Load		
Row	**Base Case Wind**	**Alt 2**	**Alt 5**	**Alt 5A**	**Alt 2**	**Alt 5**	**Alt 5A**
1	Overlay voltage violations: All facilities in-service	0	0	0	0	0	0
2	Overlay thermal violations: All facilities in-service	0	0	0	0	0	0
3	Overlay unsolvable: Overlay N-1	2	0	0	0	0	0
4	Overlay thermal violations: Overlay N-1	0	0	0	0	0	0
5	Overlay voltage violations: Overlay N-1	2	2	2	2	2	2
6	Existing System Thermal violations: All facilities in-service	11	13	14	0	0	0
7	Existing System unsolvable: All N-1	22	16	18	11	9	6
8	Existing System thermal violations: Overlay N-1	9	33	14	2	3	4
9	Existing System thermal violations: Existing System N-1	146	283	187	57	80	72

4.9.2 High Gas Future Sensitivity Analysis

The results in **Table 4-13** indicate that for the Low Wind case, there are no unsolvable contingencies (Row 3) in the EHV overlay. For the High Wind and SPP Import sensitivities, the results show several unsolved contingencies (Row 3) for all three alternatives. The High Wind and SPP Import results indicate the transmission network is stressed and is exceeding its capacity. The locations and magnitude of new wind farms and gas generation facilities as well as load growth should be monitored as they could have a significant impact on the results.

Table 4-13: High Gas Future Results – Generation Sensitivities

		High Wind			Imports from SPP			Low Wind		
Row	**Number of Violations**	**Alt 2**	**Alt 5**	**Alt 5A**	**Alt 2**	**Alt 5**	**Alt 5A**	**Alt 2**	**Alt 5**	**Alt 5A**
1	Overlay voltage violations: All facilities in-service	0	0	0	0	0	0	0	1	1
2	Overlay thermal violations: All facilities in-service	0	1	1	0	0	0	0	0	0
3	Overlay unsolvable: Overlay N-1	18	15	13	15	24	27	0	0	0
4	Overlay thermal violations: Overlay N-1	3	1	1	0	0	0	0	0	0
5	Overlay voltage violations: Overlay N-1	2	2	1	4	0	0	8	2	3
6	Existing System Thermal violations: All facilities in-service	14	20	20	5	7	6	2	0	0
7	Existing System unsolvable: All N-1	12	13	8	19	34	43	3	2	1
8	Existing System thermal violations: Overlay N-1	10	41	41	4	13	12	0	1	1
9	Existing System thermal violations: Existing System N-1	87	151	125	85	94	97	16	13	16

Table 4-14: High Gas Future Results – Load Sensitivities

		High Load		
Row	**Number of Violations**	**Alt 2**	**Alt 5**	**Alt 5A**
1	Overlay voltage violations: All facilities in-service	0	0	0
2	Overlay thermal violations: All facilities in-service	0	0	0
3	Overlay unsolvable: Overlay N-1	1	0	0
4	Overlay thermal violations: Overlay N-1	0	0	0
5	Overlay voltage violations: Overlay N-1	2	3	3
6	Existing System Thermal violations: All facilities in-service	13	12	11
7	Existing System unsolvable: All N-1	18	17	19
8	Existing System thermal violations: Overlay N-1	2	3	7
9	Existing System thermal violations: Existing System N-1	90	98	134

4.9.3 Low Carbon Future Sensitivity Analysis

The High Wind and SPP Import sensitivities in the Low Carbon Future shown in **Table 4-15** show several unsolved contingencies (Row 3) for all three alternatives. These results are indicative of a transmission network that is stressed and is exceeding its capability. The results indicate that there are no unsolvable contingencies in the EHV overlay for the Low Wind case. The locations and magnitude of new wind farms and coal plant retirements as well as load growth should be monitored as they could have a significant impact on the results.

Table 4-15: Low Carbon Future Results – Generation Sensitivities

		High Wind			Imports from SPP			Low Wind		
Row	**Number of Violations**	**Alt 2**	**Alt 5**	**Alt 5A**	**Alt 2**	**Alt 5**	**Alt 5A**	**Alt 2**	**Alt 5**	**Alt 5A**
1	Overlay voltage violations: All facilities in-service	0	0	0	0	0	0	0	0	0
2	Overlay thermal violations: All facilities in-service	0	0	0	0	0	0	0	0	0
3	Overlay unsolvable: Overlay N-1	69	27	42	10	9	15	0	0	1
4	Overlay thermal violations: Overlay N-1	0	2	2	3	0	0	1	1	1
5	Overlay voltage violations: Overlay N-1	0	0	1	2	0	2	8	6	7
6	Existing System Thermal violations: All facilities in-service	8	14	12	2	7	7	2	3	3
7	Existing System unsolvable: All N-1	231	10	104	1	3	5	1	1	2
8	Existing System thermal violations: Overlay N-1	1	15	19	17	21	14	5	1	0
9	Existing System thermal violations: Existing System N-1	227	163	108	135	60	57	26	17	16

Table 4-16: Low Carbon Future Results – Load Sensitivities

		High Load		
Row	**Number of Violations**	**Alt 2**	**Alt 5**	**Alt 5A**
1	Overlay voltage violations: All facilities in-service	0	0	0
2	Overlay thermal violations: All facilities in-service	0	0	0
3	Overlay unsolvable: Overlay N-1	0	0	1
4	Overlay thermal violations: Overlay N-1	0	0	0
5	Overlay voltage violations: Overlay N-1	3	3	3
6	Existing System Thermal violations: All facilities in-service	14	15	16
7	Existing System unsolvable: All N-1	12	13	14
8	Existing System thermal violations: Overlay N-1	10	5	14
9	Existing System thermal violations: Existing System N-1	197	160	191

5 Summary of Revised Alternatives

Based on the combined cost and performance analysis, three alternatives were selected for future evaluation. **Table 5-1** shows a high level summary of these optimized alternatives. Alternative 2 has approximately 4,500 miles of 345 kV line and 4,000 miles of 765 kV line, while alternatives 5 and 5A have approximately 7,800 and 7,000 miles of 765 kV line. While Alternative 5 does not consist of any overhead HVDC line, Alternative 5A includes nearly 400 miles. Similarly Alternative 2 has approximately the same number of new 345 kV and 765 kV buses, while Alternatives 5 and 5A only have 5 new 345 kV buses, but approximately 45 new 765 kV buses.

Table 5-2 applies the estimated component costs found in Table 4-4 to calculate an estimated cost for each of the alternatives.

Table 5-1: High Level Summary of Revised Alternatives

High Level Summary	Alt 2	Alt 5	Alt 5A
Number of 345 kV new Lines, single circuit.	5	0	0
Total Single Circuit miles 345 lines	245	0	0
Total Structure miles of 345 double circuit lines	4,409	80	80
Number of 765 kV new Lines, single circuit.	32	53	49
Total Circuit miles length of 765 lines	3,950	7,773	7,066
Number of 765/345 kV Transformers	21	40	40
Number of 230/345 kV Transformers	1	1	1
Number of River Crossing lines	5	8	8
HVDC Underwater Cable Circuit miles	64	91	91
HVDC Overhead Cable Circuit miles	200	0	385
Number of 345 kV new buses or connection to existing buses	34	5	5
Number of 765 kV new buses or connection to existing buses	32	46	44

Figure 5-1: Cost Estimates for Conceptual Alternatives

Element	$M
Transmission Lines (includes right-of-way costs)	
Single circuit 345 kV (USD / mile)	1.50
Double circuit 345 kV (USD / mile)	1.97
Single circuit 765 kV (USD / mile)	2.71
Transformers	
345/230 kV, 500 MVA (USD / unit)	6.5
765/345 kV, 1000 MVA (USD / unit)	12.0
765/345 kV, 2250 MVA (USD / unit)	21.0
Network Stations (does not include land costs)	
345 kV (USD / station)	11.8
765 kV (USD / station)	25.1
Major River crossings	7.0
HVDC Undersea Cable (USD / mile)	9.0
HVDC Overhead (USD /mile)	5.0
Reactive Correction	
Shunt reactors (USD / MVAr)	0.0420

Table 5-2: Cost summary for Revised Alternatives

Line Costs in Millions of Dollars	Alt 2	Alt 5	Alt 5A
Estimated Cost for 345 kV Lines	$9,053	$158	$158
Estimated Cost for 765 kV Lines	$10,705	$21,066	$19,149
Total Cost Transmission Lines	$19,758	$21,224	$19,307
Transformers Costs			
Estimated Cost of 765/345 kV Transformers	$445	$848	$848
Estimated Cost of 230/345 kV Transformers	$7	$7	$7
Total Costs Transformation	$452	$855	$855
Network Substation/Station Costs 345 kV	$472	$59	$59
Network Substation/Station Costs 765 kV	$552	$879	$853
Total cost	$1,024	$938	$912
River Crossing line costs	$35	$56	$56
HVDC Costs	$1,427	$1,281	$2,500
Shunt Reactors	$1,115	$1,413	$1,205
Total Estimated Costs	$23,811	$25,767	$24,835

6 Sequencing of Alternatives

6.1 Sequencing Approach

This section describes the SMARTransmission study sequencing approach as well as the results. The goal of the sequencing approach was to determine the build out required in 2019 and 2024 that would facilitate the development of the optimized 2029 transmission alternatives. The study sponsors first defined optimal system alternatives for 2029. The 2029 alternatives were then used to develop transmission the overlays for 2024 as described below.

1. Wind interconnection locations as shown in **Figure 3-1** were not modified. Nameplate values were reduced on a prorated basis for 2024 based on renewable energy requirements shown in **Table 6-2.**
2. Based on these changes, lightly loaded lines were removed from 2029 revised EHV transmission overlay alternatives.
3. Using an iterative process, the 2024 overlay alternatives were tested for N-1 contingencies to ensure the reliability of the system.
4. The 2024 overlays were finalized based on the results from Step 3.
5. The 2024 overlay alternatives were tested for N-2 contingencies to evaluate the robustness of the overlays.

The above process was repeated to create 2019 overlays from the final 2024 overlays. Several factors could impact the results of the actual sequencing. Locations and magnitude of generation additions and retirements as well as load growth should be monitored as they could have a significant impact on the results.

6.2 Summary of RPS Values Used in Study

Table 6-1 shows the SMARTransmission assumptions for the RPS requirement by state for 2029, 2024, and 2019. The highlighted values were taken from the Database of State Incentives for Renewable and Efficiency website. Other values were extrapolated.

Table 6-1: RPS Requirements by State for Study Years 2029, 2024, 2019

Year	IA	IL	IN	MI	MN	MO	ND	NE	OH	SD	WI	Avg
2029	20.0%	25.0%	20.0%	20.0%	28.0%	20.0%	20.0%	20.0%	25.0%	20.0%	25.0%	22%
2024	15.0%	23.5%	15.0%	15.0%	25.0%	15.0%	16.0%	15.0%	25.0%	16.0%	24.0%	19%
2019	12.5%	16.0%	12.5%	12.5%	20.0%	12.5%	12.5%	12.5%	15.0%	12.5%	19.0%	14%
2015	10.0%	10.0%	10.0%	10.0%	15.0%	10.0%	10.0%	10.0%	5.0%	10.0%	13.0%	10%

The nameplate generation in **Table 6-2** was calculated using the same methodology as the 2029 Base Case Wind in Section 2.1.

Table 6-2: Nameplate Installed Wind Generation by State for Study Years 2029, 2024, 2019

	Base Case Wind			Low Wind			High Wind		
State	2029	2024	2019	2029	2024	2019	2029	2024	2019
IA	6,694	5,753	4,696	5,078	4,869	4,102	7,684	6,331	4,969
IL	7,919	6,774	4,486	5,026	4,774	3,466	10,198	8,641	5,446
IN	3,577	2,905	2,482	1,035	1,035	1,035	4,537	3,351	2,703
MI	8,201	5,852	4,640	3,519	3,466	3,415	10,186	6,919	5,222
MN	5,876	5,082	3,869	5,042	4,967	4,448	7,298	6,009	4,354
MO	3,070	2,357	1,555	1,845	1,686	1,104	3,821	2,795	1,762
ND	4,833	3,783	2,602	3,029	2,795	1,938	5,939	4,428	2,906
NE	5,196	3,893	2,429	2,958	2,668	1,606	6,567	4,693	2,806
OH	4,729	4,500	2,570	4,059	3,999	2,365	5,873	5,320	2,893
SD	4,208	3,196	2,057	2,469	2,243	1,417	5,274	3,818	2,351
WI	2,506	2,483	1,998	2,061	1,852	1,686	3,152	2,859	2,169
Total	56,809	46,579	33,384	36,121	34,355	26,582	70,528	55,164	37,581

6.3 2024 Sequencing of Alternatives

As discussed in Section 5.1, the 2029 revised EHV transmission overlay alternatives were used as a basis for developing the 2024 overlays. For Alternative 5, the 765 kV line from Rockport (IN)-Kincaid (IL)-Hills (IA)-Adair County (IA)-St Joseph (MO) was not required in 2024 because the Point Beach (WI) to DC Cook (MI) HVDC line was chosen to meet the "theoretical cut set #4 transfer requirements. This sequencing can be flexible based on the final needs and locational requirements for west to east transfers. Since the HVDC line in Alternative 5A from Rockport to Adair County represents the same path, Alternative 5A is identical to Alternative 5 for the 2024 sequence. As a result, there was no need to test Alternatives 5 and 5A separately. The 2024 overlays for Alternatives 2 and 5 were tested for N-1 contingencies to ensure the reliability of the system. The 2024 sequence was also tested for High Wind, Low Wind, SPP Imports, and High Load sensitivities. The results shown in **Table 6-3 and Table 6-4** indicate that the alternatives perform adequately under the 2024 sequence.

Table 6-3: 2024 Base Wind Results for On and Off Peak Cases

		Off Peak		On Peak	
Row	**Number of Violations**	**Alt 2**	**Alt 5**	**Alt 2**	**Alt 5**
1	Overlay voltage violations: All facilities in-service	0	0	0	0
2	Overlay thermal violations: All facilities in-service	0	0	0	0
3	Overlay unsolvable: Overlay N-1	0	0	0	0
4	Overlay thermal violations: Overlay N-1	0	0	0	0
5	Overlay voltage violations: Overlay N-1	3	1	0	1
6	Existing System Thermal violations: All facilities in-service	3	11	0	0
7	Existing System unsolvable: All N-1	5	5	10	9
8	Existing System thermal violations: Overlay N-1	4	6	0	0
9	Existing System thermal violations: Existing System N-1	29	17	45	69

Table 6-4: 2024 Base Wind Results – Generation Sensitivities

		High Wind		SPP Imports		Low Wind		High Load	
Row	**Number of Violations**	**Alt 2**	**Alt 5**	**Alt 2**	**Alt 5**	**Alt 2**	**Alt 5**	**Alt 2**	**Alt 5**
1	Overlay voltage violations: All facilities in-service	0	0	0	0	0	0	0	0
2	Overlay thermal violations: All facilities in-service	0	0	0	0	0	0	0	0
3	Overlay unsolvable: Overlay N-1	11	4	1	2	0	0	0	0
4	Overlay thermal violations: Overlay N-1	0	2	0	0	0	0	0	0
5	Overlay voltage violations: Overlay N-1	9	3	1	0	4	29	0	0
6	Existing System Thermal violations: All facilities in-service	10	6	7	5	2	3	0	0
7	Existing System unsolvable: All N-1	6	4	3	3	2	3	13	15
8	Existing System thermal violations: Overlay N-1	17	28	1	18	0	1	0	0
9	Existing System thermal violations: Existing System N-1	198	90	31	22	13	9	86	83

Figure 6-1 shows 2024 sequencing for Alternative 2, the combination 345 kV and 765 kV alternative. The dashed black lines represent the lines that were removed from the 2029 Alternative 2 topology.

Figure 6-1: Alternative 2 Showing Lines to be Removed for 2024 Revised EHV Transmission Overlay

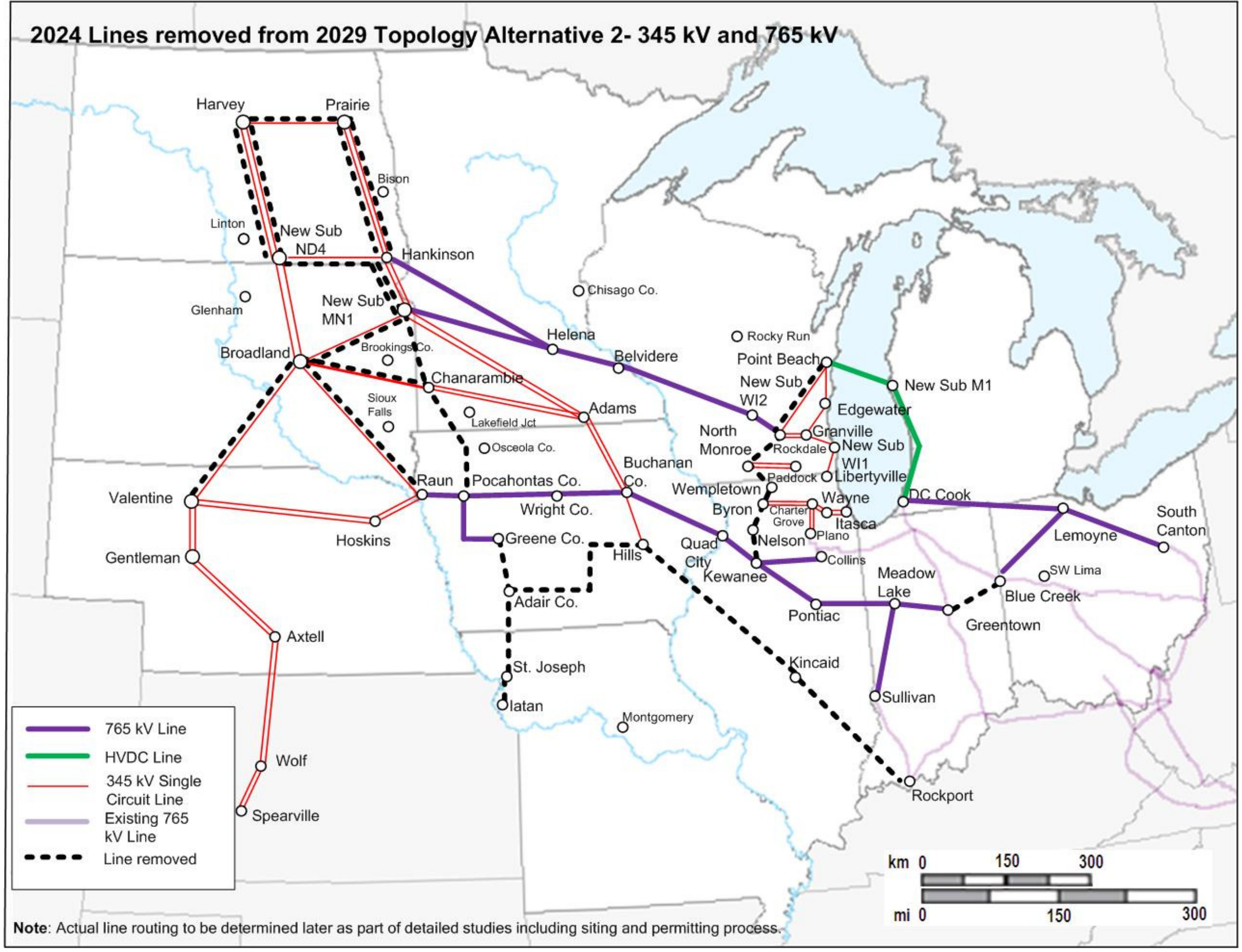
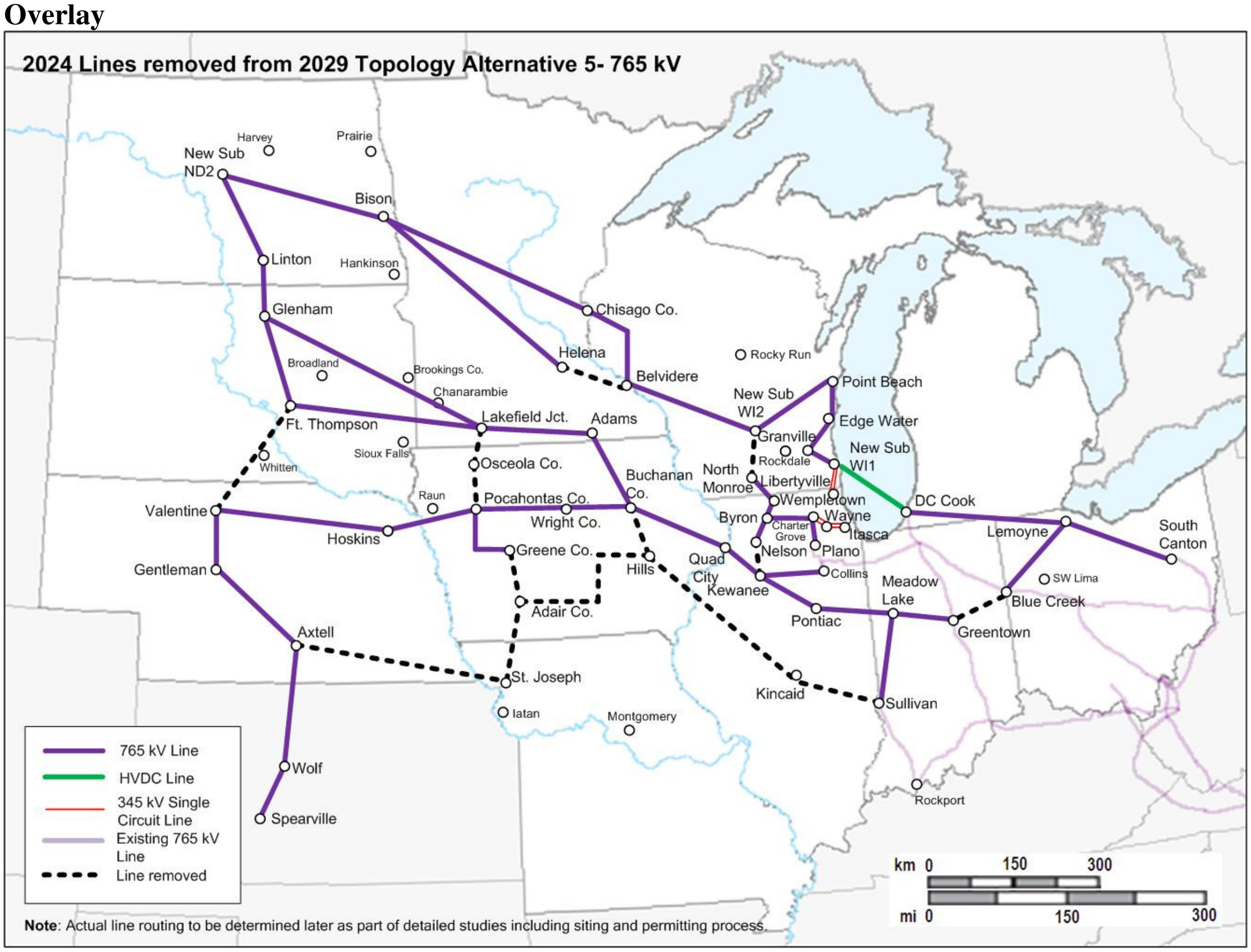


Figure 6-2 shows 2024 sequencing for Alternative 5, the 765 kV-only alternative. The dashed black lines represent the lines that were removed from the 2029 Alternative 5 topology.

Figure 6-2: Alternative 5 Showing Lines to be Removed for 2024 Revised EHV Transmission Overlay



6.3.1 2024 Double Contingency Analysis

Double contingency (N-2) analysis was performed on the 2024 off peak model. The sponsor group chose off peak models to perform the analysis since off peak periods are characterized by high wind generation, low consumer loads, and heavily loaded EHV facilities. The double contingencies were simulated on the revised EHV transmission overlay and existing 765 kV elements. Using generation re-dispatch, N-1-1 contingency analysis was simulated for those N-2 contingencies that resulted in non-convergent solutions. Approximately 2.4 GW of generation was curtailed in North and South Dakota for the outages of Hankinson (ND) to Helena (MN) and New Sub MN1 (MN) to Helena (MN) 765 kV lines in Alternative 2. Similarly, approximately 1.3 GW of generation was re-dispatched in North Dakota, Minnesota and Iowa for Bison (ND) to Helena (MN) and Bison (MN) to Chisago County (MN) 765 kV line outages in Alternative 5. Numerous non-solving contingencies were noted on the existing system. These are expected to be addressed by generation re-dispatch and should be further evaluated for feasibility in planning studies.

6.4 2019 Sequencing of Alternatives

As discussed in Section 5.1, the 2024 revised EHV transmission overlay alternatives were used as a basis for developing the 2019 overlays. The 2019 overlays were tested for N-1 contingencies to ensure the reliability of the system. The 2019 sequence was also tested for High Wind, Low Wind, SPP Imports, and High Load sensitivities. The results shown in **Table 6-5** and **Table 6-6** indicate that the alternatives perform adequately under the 2019 sequence.

Table 6-5: 2019 Base Wind Results for On and Off peak Cases

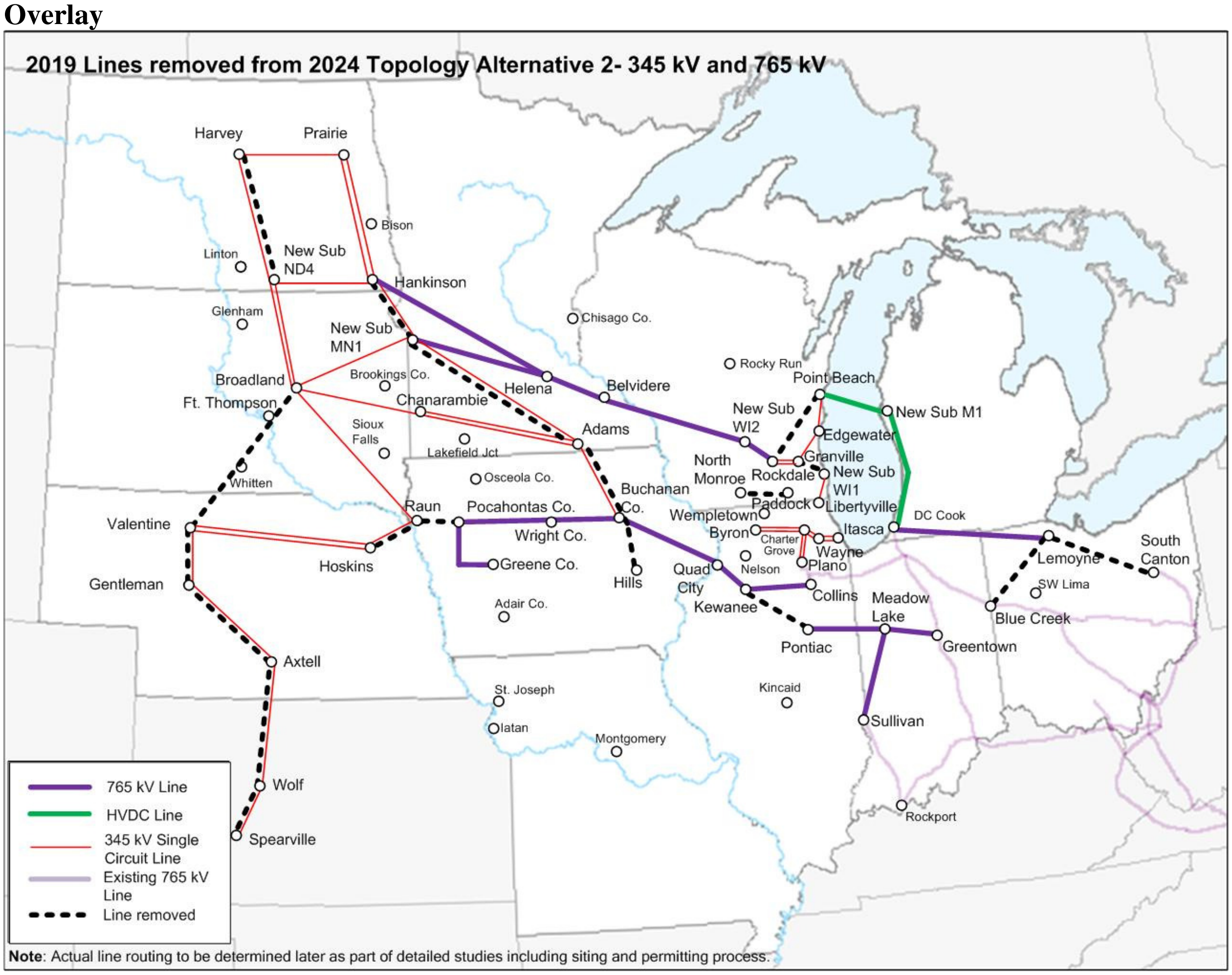
		Off Peak		On Peak	
Row	**Number of Violations**	**Alt 2**	**Alt 5**	**Alt 2**	**Alt 5**
1	Overlay voltage violations: All facilities in-service	0	1	0	0
2	Overlay thermal violations: All facilities in-service	0	0	0	0
3	Overlay unsolvable: Overlay N-1	0	0	0	0
4	Overlay thermal violations: Overlay N-1	0	0	0	0
5	Overlay voltage violations: Overlay N-1	4	0	0	0
6	Existing System Thermal violations: All facilities in-service	2	2	0	0
7	Existing System unsolvable: All N-1	3	3	5	5
8	Existing System thermal violations: Overlay N-1	5	20	0	0
9	Existing System thermal violations: Existing System N-1	34	13	31	44

Table 6-6: 2019 Base Wind Results – Generation Sensitivities

		High Wind		SPP Imports		Low Wind		High Load	
Row	**Number of Violations**	**Alt 2**	**Alt 5**	**Alt 2**	**Alt 5**	**Alt 2**	**Alt 5**	**Alt 2**	**Alt 5**
1	Overlay voltage violations: All facilities in-service	0	0	0	1	0	1	0	0
2	Overlay thermal violations: All facilities in-service	0	0	0	0	0	0	0	0
3	Overlay unsolvable: Overlay N-1	1	4	0	1	0	0	0	0
4	Overlay thermal violations: Overlay N-1	1	2	0	0	0	0	0	0
5	Overlay voltage violations: Overlay N-1	3	4	3	1	7	0	0	0
6	Existing System Thermal violations: All facilities in-service	2	3	2	2	2	0	0	0
7	Existing System unsolvable: All N-1	4	7	4	5	3	2	38	39
8	Existing System thermal violations: Overlay N-1	0	2	4	7	0	1	1	4
9	Existing System thermal violations: Existing System N-1	11	21	30	17	16	15	57	78

Figure 6-3 shows 2019 sequencing for Alternative 2, the combination 345 kV and 765 kV alternative. The dashed black lines represent transmission lines that were removed from the 2024 Alternative 2 topology.

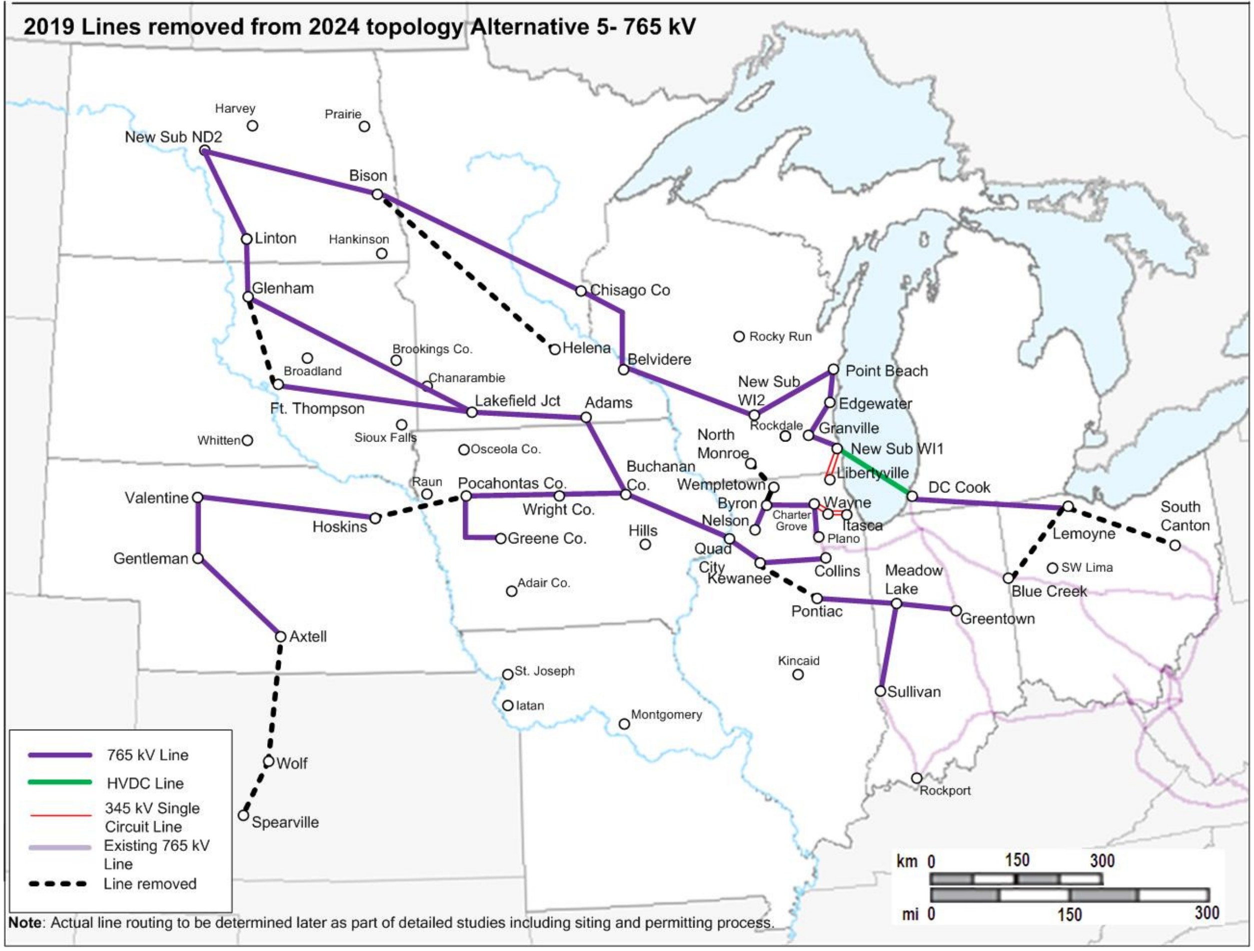
Figure 6-3: Alternative 2 Showing Lines to be Removed for the 2019 Revised EHV Transmission Overlay



Note: Actual line routing to be determined later as part of detailed studies including siting and permitting process.

Figure 6-4 shows 2019 sequencing for Alternative 5, the 765 kV-only alternative. The dashed black lines represent the lines that were removed from the 2024 Alternative 5 topology.

Figure 6-4: Alternative 2 Showing Lines to be Removed for the 2019 Revised EHV Transmission Overlay



Note: Actual line routing to be determined later as part of detailed studies including siting and permitting process.

6.4.1 Double Contingency Analysis

Double contingency (N-2) analysis was performed on the 2019 off peak model. The sponsor group chose off peak models to perform the analysis since off peak periods are characterized by high wind generation, low consumer loads, and heavily loaded EHV facilities. The double contingencies were simulated on the revised EHV transmission overlays and the existing 765 kV elements. Using generation re-dispatch, N-1-1 contingency analysis was simulated for those N-2 contingencies that resulted in non-convergent solutions. For example, approximately 1.4 GW of generation was curtailed in North and South Dakota for the Hankinson (ND) to Helena (MN) and New Sub MN1 (MN) to Helena (MN) 765 kV line outages in Alternative 2 to obtain a convergent solution. Similarly, approximately 1.5 GW of generation had to be re-dispatched in North and South Dakota for the Bison (ND) to Helena (MN) and Bison (ND) to Chisago County (MN) 765 kV line outages in Alternative 5. Numerous reliability issues associated with N-2 analysis were seen on the existing system. These are expected to be addressed by generation re-dispatch and should be further evaluated for feasibility in planning studies.

7 Phase 2: Economic Benefits Evaluation

Phase 2 will be used to study the economic benefits of the revised EHV transmission overlay Alternatives. The work will compare the revised alternatives and rank them by performance. PROMOD by Ventyx will be used as the security constrained economic dispatch software, and the 2019 Regional Generation Outlet Study (RGOS) production model developed by MISO will be used as the starting point to build the SMARTransmission production models.

Phase 2 metrics that will be studied include:

- The Adjusted Production Cost (APC) is a measure of the impact on production cost by nodal LMPs, accounting for purchases and sales of economic energy interchange. This metric is typically simulated by a production cost modeling tool accounting for 8,760 hourly profiles per year of commitment and dispatch modeling, taken over the course of the study period.

- The Environmental Costs include SO_2, NO_{X}, and CO_2. The pricing for SO_2 and NO_X is approximated using data from the RGOS model which represents our best estimate of current market prices.

- Load Cost is also referred to as load payment. It is the zonal LMP based total energy cost to consumers. Hourly load-weighted average LMP price for each zone is calculated and multiplied with the zonal load to determine the hourly zonal load payment. The zonal annual load payment is then the sum of all 8760 hourly load payments.

- The Annual Project Cost is calculated on zonal level as follows:

  Annual Project Cost = 70% * Annual APC + 30% * Annual Load Cost

  The 70% APC / 30% Load Cost calculation is consistent with the Midwest ISO's economic analysis process and represents a rough approximation of the percentage of the study footprint under regulated retail rates (70%) and the percentage of the study footprint with a deregulated retail market (30%).

8 Conclusion

Transmission infrastructure is critical to the interconnection and delivery of energy. SMARTransmission seeks to ensure that the system is efficient and capable of interconnecting wind and other generation resources. The revised EHV transmission overlay alternatives developed in Phase 1 are designed to reliably and efficiently integrate 56.8 GW of wind energy in the Midwest and help states to satisfy renewable energy standards and goals.

Throughout the study, the SMARTransmission sponsors have shared the results with the Midwest Independent Transmission System Operator, PJM Interconnection and Southwest Power Pool to serve as input to their regional transmission planning processes. These Regional Transmission Organizations will make the final decisions with regard to the scope and timing of transmission projects and will identify required projects.

Contingency analysis performed as part of Phase 1 indicates that revised Alternative 2 and Alternative 5 performed adequately with all transmission facilities in service and single contingency conditions for the base wind model (56.8 GW). While some N-1 violations were identified on the underlying system, those violations are generally a function of load growth and wind resource locations. Violations on the underlying system for N-2 contingencies are expected to be addressed with re-dispatch and local planning upgrades. Planning studies will be required to determine the upgrades needed to integrate a transmission overlay into existing systems. While these revised alternatives demonstrated improved performance over the other conceptual designs considered in the first phase of the study, the projects included in these alternatives do not preclude different long-range projects that accomplish similar system performance to the projects in these alternatives.

To identify a potential build out for 2019 and 2024, the sponsor team developed a sequencing approach for each of the revised EHV transmission overlay alternatives. The sequencing was designed to help prioritize projects in order to efficiently develop the 2029 transmission alternatives. Locations and magnitude of generation additions and retirements, as well as load growth, should be monitored as they could have a significant impact on the direction of the actual sequencing. The phasing alternatives do not preclude alternative phasing and short-range projects that accomplish similar system performance.

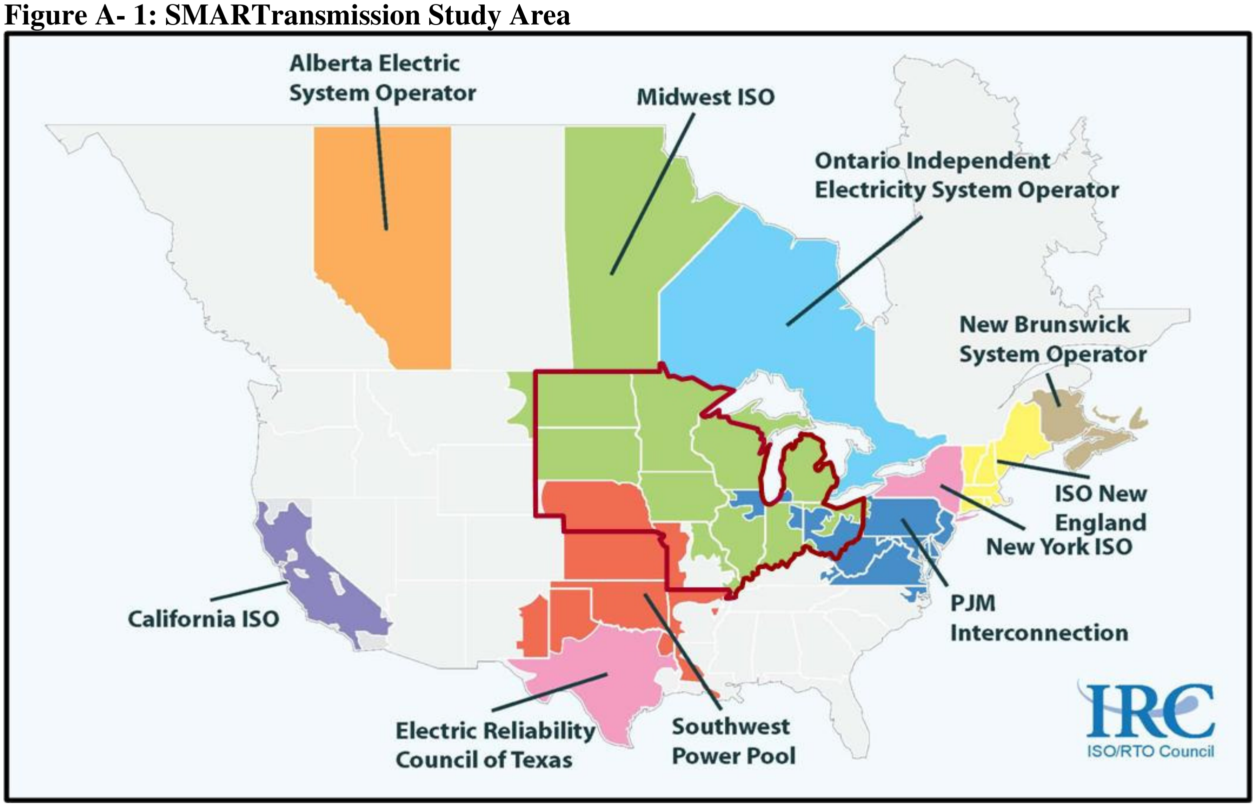
The SMART study analyzed transmission system needs from a regional perspective over a study area that encompasses some of the country’s best wind resources. The information derived from this analysis is being used to recommend an EHV transmission overlay solution that can be integrated with the existing transmission system in areas of North and South Dakota, Iowa, Indiana, Ohio, Illinois, Michigan, Minnesota, Nebraska, Missouri and Wisconsin. The full scope of benefits expected from the EHV transmission overlay alternatives will be evaluated in Phase 2.

A Appendix A: Key Assumptions

A.1 Study Area

The SMARTransmission Study focuses on areas within North and South Dakota, Iowa, Indiana, Ohio, Illinois, Minnesota, Missouri, Nebraska, Michigan, and Wisconsin as shown within the demarcated line in Figure A- 1. The Study area is spread across three Regional Transmission Organizations (RTOs) – Midwest ISO, PJM and SPP.

Figure A- 1: SMARTransmission Study Area



The 36 control areas included in the Study area are listed in Table A - 1.

Table A - 1: Control Areas and Associated Codes and Numbers

Ref	RTO	Planning Region	Area Code	Area Name	Area #
1	Midwest ISO	West	ALTW	Alliant Energy West	627
2			ALTE	Alliant Energy East	694
3			WEC	Wisconsin Energy Corporation	295
4			WPS	Wisconsin Public Service Corporation	696
5			MGE	Madison Gas & Electric	697
6			UPPC	Upper Peninsula Power Co.	698
7			XEL	Excel Energy Services Inc.	600
8			DPC	Dairyland Power Cooperative	680
9			MP	Minnesota Power, Inc	608
10			SMMPA	Southern MN Municipal Power Association	613
11			GRE	Great River Energy	615
12			OTP	Otter Tail Power Company	620
13			MDU (in WAPA)	Montana-Dakota Utilities	661
14		Central	HE	Hoosier Energy Rural Electric	207
15			DEM	Duke Energy Midwest (Cinergy)	208
16			Vectren	Vectren (Southern Indiana Gas & Electric)	210
17			IP&L	Indianapolis Power & Light	216
18			CWLD	Columbia Water and Light	333
19			AmerenMO	Ameren MO	356
20			AmerenIL	Ameren IL	357
21			CWLP	City Water Light & Power	360
22			SIPC	Southern Illinois Power Cooperative	361
23			MPW	Muscatine Power & Water	633
24			MEC	MidAmerican Energy Company	635
25		East	FE	First Energy	202
26			NIPSCo	Northern Indiana Public Service Company	217
27			METC	Michigan Electric Transmission Company	218
28			ITC	International Transmission Company	219
29	PJM		CE	Commonwealth Edison (ComEd)	222
30			AEP	American Electric Power	205
31			DAY	Dayton Power and Light	209
32	SPP		NPPD	Nebraska Public Power District	640
33			OPPD	Omaha Public Power District	645
34			LES	Lincoln Electric System	650
35	N/A		OVEC	Ohio Valley Electric Corporation	206
36			WAPA	Western Area power Administration	652

A.2 Time frame

The Study seeks to assess transmission system needs in 2029. After the 2029 EHV Overlay alternatives were defined, transmission upgrade requirements for 2019 and 2024 were developed. This sequencing process was used to facilitate an efficient build out of the transmission overlay in an effort to preclude the development of a piecemeal transmission system that only considers immediate needs.

A.3 2029 Energy Requirements

Energy usage by state was obtained from the EIA website for 1990-2007. For each state in the study area, (except Wisconsin which used 1.1%), usage was inflated by 1.0% annually through 2029. Table A - 2 calculates the total 2029 energy requirements for the study area and the amount of that energy that will be supplied by wind generation based on the RPS considered for the states. The basis for the information provided in the table is explained in Section 3.1.1 of the main report.

Table A - 2: Energy Required by State for Base Wind 2029

	IA	**IL**	**IN**	**MI**	**MN**	**MO**	**ND**	**NE**	**OH**	**SD**	**WI**
Federal 20% - State RPS - Utility RPS in %	20%	25%	20%	20%	28%	20%	20%	20%	25%	20%	25%
% of energy renewable from wind (MWh)	80%	75%	80%	80%	80%	80%	80%	80%	50%	80%	65%
Average Capacity Factor (Supplied from MISO 3 Year Capacity Factor Statistics	0.378	0.3	0.325	0.303	0.363	0.354	0.398	0.403	0.304	0.404	0.3
High Wind State- yes/no? (high wind state if capacity factor >36%)	Yes	No	No	No	Yes	No	Yes	Yes	No	Yes	No
Energy Growth (average US)	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.1%
Energy Usage by US State (MWh) / 2007 EIA	45,269,523	146,055,151	109,420,150	109,296,749	68,231,182	85,532,850	11,905,695	28,248,400	161,770,827	10,603,301	71,301,300
Total energy usage extrapolated assuming constant growth (billion MWh) (2029)	56,347,693	181,797,163	136,196,996	136,043,397	84,928,434	106,464,095	14,819,207	35,161,231	201,358,714	13,198,097	90,703,255
% for RPS renewable (MWh) -	11,269,539	45,449,291	27,239,399	27,208,679	23,355,319	21,292,819	2,963,841	7,032,246	50,339,679	2,639,619	22,675,814
RPS energy from wind (MWh)	9,015,631	34,086,968	21,791,519	21,766,944	18,684,256	17,034,255	2,371,073	5,625,797	25,169,839	2,111,696	14,739,279
Total	**172,397,256**										

A.4 2029 Wind Nameplate Values

Table A - 3 shows wind generation levels that would allow states to meet Federal and state RPS requirements. The generation is based on state wind capacities developed by NREL and in-state wind requirements. An iterative process was used to determine the excess wind generation within each state that could be exported to states that did not have adequate in-state wind resources to fulfill their RPS requirements. A detailed explanation is provided in Section 3.1.2 of the main report.

Table A - 3: Total Wind by State for Base Wind 2029

A	B	C	D	E	F	G	H	I	J
	Energy to meet ~80% RPS Requirement	**Existing Wind as of May 2009**	**Incremental wind to meet ~80% RPS Requirement**	**Incremental Wind Prorate of NREL by State**	**Energy (Import) / Export by State**	**% RPS Wind Generated In-State**	**Incremental Wind Prorate of NREL by State**	**Energy (Import) / Export by State**	**Total Wind by State Existing + Incremental**
State	MWh	MWh	(B-C) MWh	MWh	(E-D) MWh	%	MW	MW	MW
IA	9,015,631	10,109,338	(1,093,707)	12,055,001	13,148,708	100%	3,641	3,857	6,694
IL	34,086,968	4,441,320	29,645,648	16,370,614	(13,275,034)	61%	6,229	(3,894)	7,919
IN	21,791,519	2,946,645	18,844,874	7,238,053	(11,606,822)	47%	2,542	(3,404)	3,577
MI	21,766,944	342,402	21,424,541	21,424,541	0	100%	8,072	0	8,201
MN	18,684,256	5,739,683	12,944,572	12,944,572	0	100%	4,071	0	5,876
MO	17,034,255	958,221	16,076,034	8,562,158	(7,513,876)	56%	2,761	(2,204)	3,070
ND	2,371,073	2,674,130	(303,057)	14,176,611	14,479,667	100%	4,066	4,247	4,833
NE	5,625,797	540,133	5,085,664	17,801,633	12,715,968	100%	5,043	3,730	5,196
OH	25,169,839	18,641	25,151,198	12,575,599	(12,575,599)	50%	4,722	(3,689)	4,729
SD	2,111,696	1,019,244	1,092,452	13,873,332	12,780,880	100%	3,920	3,749	4,208
WI	14,739,279	1,500,588	13,238,691	5,084,796	(8,153,895)	45%	1,935	(2,392)	2,506
Total	172,397,256	30,290,346	142,106,911	142,106,911			47,002	0	56,809

A.5 Wind Energy Contribution by Wind Farms

Wind is an intermittent resource, and wind generation often has limited availability during peak hours when the load is at its highest. To account for this generation profile, the study assumes a wind contribution of 20% of the installed nameplate capacity for the summer peak case. Wind farms generally produce more energy during off peak hours than on peak hours. The Study assumed a wind contribution of 90% during those hours.

A.6 Power Flow Cases

As shown in Figure A-1, the majority of the study area is within the Midwest ISO's footprint. As a result, the Midwest ISO's Transmission Expansion Plan (MTEP) 2019 summer peak model was used as a starting point to develop summer peak cases for 2029, 2024 and 2019. The Midwest ISO power flow models are updated annually to provide current transmission system topology. Midwest ISO's models also depict neighboring transmission systems in detail.

A Midwest ISO 2019 off peak case was used to develop off peak models for 2029, 2024 and 2019. The off peak cases model loads at 70% of summer peak load conditions.

A.7 Load Forecasts

Load projection rates were based on Midwest ISO[10] and PJM[11] forecasts. Growth rates ranged from 0.85% to 1.4% and are listed by control area in Table A - 4. These values were applied to the Midwest ISO 2019 models to develop the 2029 models. Major industrial loads for 2029 were not increased from their 2019 levels. This methodology resulted in a demand increase of approximately 30 GW for the 10-year period from 2019 through 2029.

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[10] Based on Midwest ISO 2008 Load Forecasts, the calculated average annual load growth rate is approximately 1.4% from 2008 to 2017.

[11] The PJM 2008 Load Forecasts projects the peak to grow at 1.4% for the next 15 years (PJM 2008 Regional Transmission Expansion Plan).

Table A - 4: Estimated Annual Load Growth by Control Areas

Ref	**Area No**	**Area Code**	**Yearly Load Growth**
1	205	AEP	**0.85%**
2	600	XEL	**1.0%**
3	608	MP	**1.0%**
4	613	SMMPA	**1.0%**
5	615	GRE	**1.0%**
6	620	OTP	**1.0%**
7	627	ALTW	**1.0%**
8	633	MPW	**1.0%**
9	635	MEC	**1.0%**
10	640	NPPD	**1.0%**
11	645	OPPD	**1.0%**
12	650	LES	**1.0%**
13	652	WAPA	**1.0%**
14	661	MDU	**1.0%**
15	680	DPC	**1.0%**
16	694	ALTE	**1.4%**
17	357	AMIL	**1.4%**
18	356	AMMO	**1.4%**
19	222	CE	**1.4%**
20	333	CWLD	**1.4%**
21	360	CWLP	**1.4%**
22	209	DAY	**1.4%**
23	208	DEM	**1.4%**
24	202	FE	**1.4%**
25	207	HE	**1.4%**
26	216	IPL	**1.4%**
27	219	ITCT	**1.4%**
28	218	METC	**1.4%**
29	697	MGE	**1.4%**
30	217	NIPS	**1.4%**
31	206	OVEC	**1.4%**
32	210	SIGE	**1.4%**
33	361	SIPC	**1.4%**
34	698	UPPC	**1.4%**
35	295	WEC	**1.4%**
36	696	WPS	**1.4%**

A.8 Generation Retirements

All generating units were dispatched in the base cases. In the low carbon future scenario, coal units that were over 40 years old in 2010 and had a maximum capacity of 250 MW were assumed to be retired. Coal plant information is available on the EIA website[12].

A.9 Future Proxy Non-wind Generation

New generation resources were needed to meet the assumed 2029 demand increases. The following methodology was used to determine non-wind generation by state:

- The load of approximately 30 GW was increased from 2019 through 2029.
- Generation was added in the study area to meet the total incremental load of approximately 30 GW.
- Twenty percent of the 56.8 GW of wind generation (as calculated in Table 3-3) amounts to approximately 11.4 GW was added in the peak load base case.
- The remaining generation of 18.6 GW required to meet the 2029 load requirement was achieved through 18.3 GW of non-wind resources (see Table A - 5) and the deficit of 0.3 GW was handled by the slack busses in the system.

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[12] www.eia.doe.gov

Table A - 5: Non-Wind Resources

State / Area		Bus No.	Bus Name	Pmax	Fuel type
AEP-OH	AEP-OH	243208	05JEFRSO	600	Proxy unit
AEP-OH	AEP-OH	248000	06CLIFTY	1200	Proxy unit
AEP-OH	AEP-OH	242935	05E LIMA	600	Proxy unit
IA	_ALTW	631139	HAZLTON3	600	ST Coal
IA	_MEC	635680	BONDRNT3	600	ST Coal
IA	_MEC	635630	BOONVIL3	184	CT Gas
IL	_AMIL	347850	7NORRIS	600	ST Coal
IL	_AMIL	348747	7BROKAW T2	600	CT Gas
IL	_AMIL	347962	7PAWNEE	450	CT Gas
MI	_METC	256196	18LTSRDJ	600	ST Coal
MI	_METC	256143	18FILRCT	120	ST Coal
MN	XEL	601011	SHERCO 3	600	ST Coal
MN	XEL	601011	SHERCO 3	600	ST Coal
MN	XEL	601001	FORBES 2	126	ST Coal
MN	_GRE	619975	GRE-WILLMAR4	450	Proxy unit
MO	_AMMO	345669	7RUSH	600	CT Gas
NE	_OPPD	645740	S3740 3	138	CT Gas
OH	_DEM	249522	08VERM M	600	CT Gas
OH	_DEM	249508	08DRESSR	600	CT Gas
OH	_DEM	249501	08BATESV	600	ST Coal
OH	_FE	238961	02MIDWAY	600	CT Gas
OH	_FE	238569	02BEAVER	600	CT Gas
OH	_FE	239092	02SAMMIS	600	ST Coal
SD	SDND	652519	OAHE 4	372	ST Coal
WI	_MGE	699157	COL 345	140	ST Coal
WI	_MGE	698928	WERNER W	600	Proxy Unit
WI	_MGE	699359	N APPLETO	600	Proxy Unit
WI	_WPS	699785	ROCKY RN	600	CT Gas
IN	DEM	249508	08DRESSR	600	CT Gas
OH-IN	AEP	242605	05CLNCHR	534	Coal
OH-IN	AEP	940300	Spor-Water Tap	1200	IGCC
OH-IN	AEP	242940	05MUSKNG	600	Coal
IN	NIPS	255108	17MCHCTY	600	ST Coal
MO	AMMO	346004	GOSCKMO1	210	CT Gas
				18324	

A.10 Reactive Load Support

Power system capacitors were added in 2029 to maintain system voltages within adequate limits (Table A - 6).

Table A - 6: Voltage Performance Criteria for Transmission Facilities 200 kV and Above

	Normal operation	
	Min	Max
ComEd	98%	103%
AEP	95%	105%
Remaining Control Areas	95%	105%

A.11 Generation Dispatch

To accommodate off peak wind generation, the output of the existing units was reduced. The following criteria were applied to the generation of the existing non-wind units:

- The dispatch of nuclear units was maintained at 100%.
- Coal units were reduced in proportion to their nameplate capacities to accommodate wind generation. Units were not reduced below their minimum required levels.
- Gas units were turned off.
- Units critical for voltage, reliability or transmission system stability were kept on-line.

A.12 Power Exports

An important premise of the SMART Study is that the energy available from 56.8 GW of wind generation is adequate to meet the RPS requirements of the study area. For on peak load levels there is no wind energy exports outside the study area. However, during off peak periods some of the wind generation will be in excess of the study area load requirements. This scenario was simulated by transferring the excess wind generation to load sinks that were created along the eastern border of the study area.

A.13 Transmission Overlay Assumptions

The following assumptions were used to develop the alternatives:

- For 765 kV lines, only single circuits were considered.
- No more than two 345 kV double circuits were considered in the same right-of-way. In practice, the double circuit lines may traverse different right-of-ways. For ease of use they are shown sharing the same right-of-ways.
- Table A - 7 shows conductor assumptions and line capabilities based on surge impedance loading:

Table A - 7: Surge Impedance Loading Reference

Nominal Voltage		**345 kV**	**2-345 kV**	**500 kV**	**765 kV**
Number and Size of Conductors per phase		2x954	2x954*	3x954	6x795
Surge Impedance Loading (MW)		390	780	910	2380
Line Length (miles)	**Line Loading (SIL)**	**Loadability in MW (No Compensation)**			
50	3.0	1170	2340	2730	7140
100	2.0	780	1560	1820	4760
150	1.6	630	1250	1460	3810
200	1.3	510	1010	1180	3090
250	1.1	430	860	1000	2620
300	1.0	390	780	910	2380
* Other conductors are used by different transmission owners and the SIL would change less than 5%.					

A.14 Thermal and Voltage Performance Criteria

Steady State load flow analysis included a single contingency analysis (N-1) of transmission facilities in the study area that have nominal voltages of 345 kV or above. Double contingency analysis (N-2) was performed on select facilities identified to be critical to the Study. Transmission facilities with nominal voltages of 200 kV or above were monitored for thermal and voltage violations.

Under normal conditions, with all transmission facilities in service, system elements with thermal loadings over 100% of their normal ratings were reported as violations. In general, facility emergency ratings were the threshold for reporting violations following single and double contingencies in the monitored control areas. AEP differs in its criteria when evaluating EHV facilities following single contingencies by requiring that the facility normal ratings are not exceeded.

Table A - 8 shows the voltage performance criteria used for facilities rated 200 kV and above.

Table A - 8: Voltage Performance Criteria for Transmission Facilities 200 kV and Above

	Normal operation		**Contingency**	
	Min	**Max**	**Min**	**Max**
ComEd	98%	103%	95%	105%
AEP	95%	105%	90%	105%
Remaining Control Areas	95%	105%	90%	110%

A.15 Performance Metrics

Each of the eight alternatives was evaluated against a predetermined set of metrics with the goal of choosing the alternatives that would provide reliable service to customers while considering both cost and the impact on the environment. The evaluation criteria included reliability assessment, total cost, transmission circuit miles[13], major river crossings, the number of new substations, system losses[14], and the number of new lines.[15] Based on the metrics, five alternatives were eliminated from further study.

A.16 Futures and Sensitivities

The assumptions detailed above were used to develop and analyze the 2029 base cases. Two other future scenarios were considered to capture the uncertainties associated with future economic and political conditions. Futures analysis was performed on Alternatives 2, 5 and 5A. To test the robustness of the alternatives, additional sensitivities, including High and Low Load Growth,

High and Low wind generation, and SPP Imports were also conducted on certain base and futures cases. A detailed description of the futures and sensitivities is provided in Appendix B. The following sections provide information on the assumptions and wind calculations for the high and low wind generation sensitivities.

A.16.1 High Wind Generation Assumptions

- Wind energy requirements were based on the RPS assumptions shown in Table 3-1 of the main report. A 20% Federal mandate was used as a starting point, and requirements were increased if state or utility mandates were higher.
- Power demand was assumed to be the same; however, energy growth was increased from 1.0% to 2.0% to calculate states' 2029 renewable energy requirements (Table A - 9).

The process used to determine the wind nameplate capacity by state was similar to that used for the base cases (Table 3-4 in the main report

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[13] Circuit miles are a key driver of total cost. They were used as a proxy to assess land owner issues.
[14] The impact of the overlay on the required generation resources.
[15] Number of Lines were used as a proxy to assess community concerns.

Table A - 9: RPS Requirement by State for High Wind in 2029

State	**IA**	**IL**	**IN**	**MI**	**MN**	**MO**	**ND**	**NE**	**OH**	**SD**	**WI**
Federal 20% - State RPS - Utility RPS in %	20%	25%	20%	20%	28%	20%	20%	20%	25%	20%	25%
% of energy renewable from wind (MWh)	80%	75%	80%	80%	80%	80%	80%	80%	50%	80%	65%
Average Capacity Factor (Supplied from Midwest ISO 3 Year Capacity Factor Statistics	0.378	0.3	0.325	0.303	0.363	0.354	0.398	0.403	0.304	0.404	0.3
High Wind State- yes/no? (High wind state if CF>36%)	Yes	No	No	No	Yes	No	Yes	Yes	No	Yes	No
Energy Growth (average US)	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%
Energy Usage by US State (MWh) / 2007 EIA	45,269,523	146,055,151	109,420,150	109,296,749	68,231,182	85,532,850	11,905,695	28,248,400	161,770,827	10,603,301	71,301,300
Total energy usage extrapolated assuming constant growth (MWh) (2029)	69,985,762	225,798,294	169,161,327	168,970,552	105,484,020	132,232,047	18,405,962	43,671,452	250,094,410	16,392,488	110,230,360
% for RPS renewable (MWh)	13,997,152	56,449,574	33,832,265	33,794,110	29,008,106	26,446,409	3,681,192	8,734,290	62,523,602	3,278,498	27,557,590
RPS energy from wind (MWh)	11,197,722	42,337,180	27,065,812	27,035,288	23,206,484	21,157,128	2,944,954	6,987,432	31,261,801	2,622,798	17,912,434
Total	**213,729,034**										

Table A - 10: Total Wind Capacity by State for High Wind in 2029

A	B	C	D	E	F	G	H	I	J
	Energy to meet ~80% RPS Requirement	**Existing Wind**	**Incremental wind to meet ~80% RPS**	**Incremental Wind Prorate of NREL by State**	**Energy Import/Export by State**	**% RPS Wind Energy Generated In State**	**Incremental Wind Prorate of NREL by State**	**Import / Export by State**	**Total Wind by State Existing + Incremental**
State	**MWh**	**MWh**	**(B-C) MWh**	**MWh**	**(E-D) MWh**	**%**	**MW**	**MW**	**MW**
IA	11,197,722	10,109,338	1,088,384	15,333,335	14,244,951	100%	4,631	4,178	7,684
IL	42,337,180	4,441,320	37,895,860	22,358,558	(15,537,303)	63%	8,508	(4,557)	10,198
IN	27,065,812	2,946,645	24,119,167	9,970,020	(14,149,148)	48%	3,502	(4,150)	4,537
MI	27,035,288	342,402	26,692,886	26,692,886	0	100%	10,057	0	10,186
MN	23,206,484	5,739,683	17,466,801	17,466,801	0	100%	5,493	0	7,298
MO	21,157,128	958,221	20,198,906	10,890,620	(9,308,286)	56%	3,512	(2,730)	3,821
ND	2,944,954	2,674,130	270,824	18,031,912	17,761,088	100%	5,172	5,209	5,939
NE	6,987,432	540,133	6,447,300	22,642,752	16,195,452	100%	6,414	4,750	6,567
OH	31,261,801	18,641	31,243,160	15,621,580	(15,621,580)	50%	5,866	(4,582)	5,873
SD	2,622,798	1,019,244	1,603,555	17,646,158	16,042,603	100%	4,986	4,705	5,274
WI	17,912,434	1,500,588	16,411,846	6,784,083	(9,627,763)	46%	2,581	(2,824)	3,152
	213,729,034	30,290,346	183,438,689	183,438,703			60,721	0	70,528

A.16.2 2029 Low Wind Assumptions:

- Wind energy requirements were based on existing RPS mandates and goals shown in Table 3-1 of the main report.
- Power demand was assumed to be the same; however, energy growth was reduced from 1.0% to 0.3% to calculate states' 2029 renewable energy requirements. This is shown in Table A - 11.
- The methodology used to determine the wind nameplate capacity by state was similar to that used for the base case (Table 3-4). Results are shown in Table A - 12.

Table A - 11: State RPS Energy Requirements for Low Wind in 2029

State	IA	IL	IN	MI	MN	MO	ND	NE	OH	SD	WI
State RPS Only	2%	23%	0%	10%	28%	15%	10%	15%	25%	10%	24%
% of energy renewable from wind (MWh)	80%	75%	80%	80%	80%	80%	80%	80%	50%	80%	65%
Average Capacity Factor (Supplied from Midwest ISO 3 Year Capacity Factor Statistics	0.378	0.3	0.325	0.303	0.363	0.354	0.398	0.403	0.304	0.404	0.3
High Wind State- yes/no? (High wind state if CF>36%)	Yes	No	No	No	Yes	No	Yes	Yes	No	Yes	No
Energy Growth (average US)	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%
Energy Usage by US State (MWh) / 2007 EIA	45,269,523	146,055,151	109,420,150	109,296,749	68,231,182	85,532,850	11,905,695	28,248,400	161,770,827	10,603,301	71,301,300
Total energy usage extrapolated assuming constant growth (MWh) (2029)	47,634,519	153,685,445	115,136,538	115,006,690	71,795,753	90,001,305	12,527,679	29,724,169	170,222,148	11,157,245	75,026,262
% for RPS renewable (MWh)	952,690	35,347,652	0	11,500,669	19,743,832	13,500,196	1,252,768	4,458,625	42,555,537	1,115,724	18,006,303
RPS energy from wind (MWh)	762,152	26,510,739	0	9,200,535	15,795,066	10,800,157	1,002,214	3,566,900	21,277,769	892,580	11,704,097
Total	101,512,209										

Table A - 12: Total Wind by State for Low Wind 2029

A	B	C	D	E	F	G	H	I	J
	Energy to meet ~80% RPS Requirement	Existing Wind	Incremental wind to meet ~80% RPS	Incremental Wind Prorate of NREL by State	Energy Import/Export by State	% RPS Wind Energy Generated In State	Incremental Wind Prorate of NREL by State	Import/ Export by State	Total Wind by State Existing + Incremental
State	MWh	MWh	(B-C) MWh	MWh	(E-D) MWh	%	MW	MW	MW
IA	773,653	10,109,338	-9,335,684	6,706,604	16,042,289	100%	2,025	4,705	5,078
IL	29,250,863	4,441,320	24,809,543	8,767,692	-16,041,850	45%	3,336	-4,705	5,026
IN	0	2,946,645	0	0	0		0	0	1,035
MI	9,339,374	342,402	8,996,972	8,996,972	0	100%	3,390	0	3,519
MN	16,033,418	5,739,683	10,293,734	10,293,734	0	100%	3,237	0	5,042
MO	10,963,134	958,221	10,004,912	4,763,417	-5,241,495	52%	1,536	-1,537	1,845
ND	1,017,338	2,674,130	-1,656,792	7,886,927	9,543,719	100%	2,262	2,799	3,029
NE	4,827,634	540,133	4,287,501	9,903,649	5,616,148	100%	2,805	1,647	2,958
OH	21,598,856	18,641	21,580,215	10,790,107	-10,790,107	50%	4,052	-3,165	4,059
SD	906,049	1,019,244	-113,195	7,718,203	7,831,398	100%	2,181	2,297	2,469
WI	12,375,745	1,500,588	10,875,157	3,915,056	-6,960,100	44%	1,490	-2,041	2,061
	107,086,063	30,290,346	79,742,362	79,742,362			26,314	0	36,121

A.17 Sequencing of Alternatives

The SMARTransmission Study seeks to assess the 2029 transmission system required to accommodate the integration of 56.8 GW of wind generation. After the 2029 EHV overlay alternatives were defined, the transmission upgrades required for 2019 and 2024 were developed. The overlay alternatives were optimized and then their construction sequences were developed. This sequencing process was used to facilitate an efficient build out of the transmission overlay in an effort to preclude the development of a piecemeal transmission system that only considers immediate needs. The intermediate transmission system plans were also sensitivity tested for low and high wind, SPP Imports, and higher than forecasted load growth. Table A - 13 shows the SMARTransmission assumptions for the RPS requirement by state for 2029, 2024, and 2019. The highlighted values were taken from the state RPS information referenced in Section 3.1.1 of the main report. Other values were extrapolated.

Table A - 13: RPS Requirements by State for Study Years 2029, 2024, 2019

Year	IA	IL	IN	MI	MN	MO	ND	NE	OH	SD	WI	Average
2029	20%	25%	20%	20%	28%	20%	20%	20%	25%	20%	25%	22%
2024	15%	23.5%	15%	15%	25%	15%	16%	15%	25%	16%	24%	18%
2019	12.5%	16%	12.5%	12.5%	20%	12.5%	12.5%	12.5%	15%	12.5%	19%	14%
2015	10%	10%	10%	10%	15%	10%	10%	10%	5%	10%	13%	10%

A.17.1 2024 Base Wind Assumptions

- Wind energy requirements were based on the RPS assumptions shown in Table A - 13.

- For each state in the study area, (except Wisconsin which used 1.1%), usage was inflated by 1.0% annually through 2024. State renewable energy requirements are shown in Table A - 14.

- The 2024 wind nameplate capacity by state was calculated using the same methodology as used for the 2029 base case (shown in Table 3-4 in the main report). The results are shown in Table A - 15.

Table A - 14: RPS Energy Requirement by State for Base Wind 2024

State	IA	IL	IN	MI	MN	MO	ND	NE	OH	SD	WI
Federal 20% - State RPS - Utility RPS in %	15.0%	23.5%	15.0%	15.0%	25.0%	15.0%	15.0%	15.0%	25.0%	15.0%	24.0%
% of energy renewable from wind (MWh)	80%	75%	80%	80%	80%	80%	80%	80%	50%	80%	65%
Average Capacity Factor (Supplied from Midwest ISO 3 Year Capacity Factor Statistics	0.378	0.3	0.325	0.303	0.363	0.354	0.398	0.403	0.304	0.404	0.3
High Wind State- yes/no? (High wind state if CF>36%)	Yes	No	No	No	Yes	No	Yes	Yes	No	Yes	No
Energy Growth (average US)	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.1%
Energy Usage by US State (MWh) / 2007 EIA	45,269,523	146,055,151	109,420,150	109,296,749	68,231,182	85,532,850	11,905,695	28,248,400	161,770,827	10,603,301	71,301,300
Total energy usage extrapolated assuming constant growth (MWh) (2024)	53,612,897	172,973,763	129,586,769	129,440,624	80,806,491	101,296,933	14,099,967	33,454,705	191,585,907	12,557,536	85,875,068
% for RPS renewable (MWh)	8,041,935	40,648,834	19,438,015	19,416,094	20,201,623	15,194,540	2,114,995	5,018,206	47,896,477	1,883,630	20,610,016
RPS energy from wind (MWh)	6,433,548	30,486,626	15,550,412	15,532,875	16,161,298	12,155,632	1,691,996	4,014,565	23,948,238	1,506,904	13,396,511
Total	140,878,605										

Table A - 15: Total Wind by State for Base Wind 2024

A	B	C	D	E	F	G	H	I	J
	Energy to meet ~80% RPS Requirement	**Existing Wind**	**Incremental wind to meet ~80% RPS**	**Incremental Wind Prorate of NREL by State**	**Energy Import/Export by State**	**% RPS Wind Energy Generated In State**	**Incremental Wind Prorate of NREL by State**	**Import/Export by State**	**Total Wind by State Existing + Incremental**
State	**MWh**	**MWh**	**(B-C) MWh**	**MWh**	**(E-D) MWh**	**%**	**MW**	**MW**	**MW**
IA	6,433,548	10,109,338	-3,675,790	8,941,129	12,616,919	100%	2,700	3,701	5,753
IL	30,486,626	4,441,320	26,045,306	13,361,242	-12,684,064	58%	5,084	-3,720	6,774
IN	15,550,412	2,946,645	12,603,767	5,324,966	-7,278,802	53%	1,870	-2,135	2,905
MI	15,532,875	342,402	15,190,473	15,190,473	0	100%	5,723	0	5,852
MN	16,161,298	5,739,683	10,421,615	10,421,615	0	100%	3,277	0	5,082
MO	12,155,632	958,221	11,197,411	6,350,506	-4,846,905	60%	2,048	-1,422	2,357
ND	1,691,996	2,674,130	-982,134	10,514,715	11,496,849	100%	3,016	3,372	3,783
NE	4,014,565	540,133	3,474,432	13,203,374	9,728,942	100%	3,740	2,854	3,893
OH	23,948,238	18,641	23,929,597	11,964,799	-11,964,799	50%	4,493	-3,509	4,500
SD	1,506,904	1,019,244	487,661	10,289,775	9,802,114	100%	2,908	2,875	3,196
WI	13,396,511	1,500,588	11,895,923	5,025,908	-6,870,014	49%	1,912	-2,015	2,483
	140,878,605	30,290,346	110,588,259	110,588,499			36,772	0	46,579

A.17.2 2024 High Wind Assumptions

- The 2024 renewable energy requirements for this scenario are based on the RPS requirements outlined in Table A - 13.

- Power demand was assumed to be the same; however, energy growth was increased from 1.0% to 2.0% to calculate the renewable energy required by state in 2024 as shown in Table A - 16.

- The process for determining the wind nameplate capacity by state was similar to that used for the base cases (Table 3-4 in the main report). The results are shown in Table A - 17.

Table A - 16: RPS Energy Requirement by State for High Wind 2024

State	**IA**	**IL**	**IN**	**MI**	**MN**	**MO**	**ND**	**NE**	**OH**	**SD**	**WI**
Federal 20% - State RPS - Utility RPS in %	15%	24%	15%	15%	25%	15%	16%	15%	25%	16%	24%
% of energy renewable from wind (MWh)	80%	75%	80%	80%	80%	80%	80%	80%	50%	80%	65%
Average Capacity Factor (Supplied from Midwest ISO 3 Year Capacity Factor Statistics	0.378	0.3	0.325	0.303	0.363	0.354	0.398	0.403	0.304	0.404	0.3
High Wind State- yes/no? (High wind state if CF>36%)	Yes	No	No	No	Yes	No	Yes	Yes	No	Yes	No
Energy Growth (average US)	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%
Energy Usage by US State (MWh) / 2007 EIA	45,269,523	146,055,151	109,420,150	109,296,749	68,231,182	85,532,850	11,905,695	28,248,400	161,770,827	10,603,301	71,301,300
Total energy usage extrapolated assuming constant growth (MWh) (2029)	63,388,261	204,512,472	153,214,626	153,041,835	95,540,127	119,766,639	16,670,847	39,554,580	226,518,212	14,847,181	99,839,034
% for RPS renewable (MWh)	9,508,239	48,060,431	22,982,194	22,956,275	23,885,032	17,964,996	2,667,336	5,933,187	56,629,553	2,375,549	23,961,368
RPS energy from wind (MWh)	7,606,591	36,045,323	18,385,755	18,365,020	19,108,025	14,371,997	2,133,868	4,746,550	28,314,777	1,900,439	15,574,889
Total	166,553,235										

Table A - 17: Total Wind by State for High Wind 2024

A	B	C	D	E	F	G	H	I	J
	Energy to meet ~80% RPS Requirement	**Existing Wind**	**Incremental wind to meet ~80% RPS**	**Incremental Wind Prorate of NREL by State**	**Energy Import/Export by State**	**% RPS Wind Energy Generated In State**	**Incremental Wind Prorate of NREL by State**	**Import/Export by State**	**Total Wind by State Existing + Incremental**
State	**MWh**	**MWh**	**(B-C) MWh**	**MWh**	**(E-D) MWh**	**%**	**MW**	**MW**	**MW**
IA	7,606,591	10,109,338	-2,502,747	10,854,505	13,357,251	100%	3,278	3,918	6,331
IL	36,045,323	4,441,320	31,604,003	18,267,114	-13,336,889	63%	6,951	-3,912	8,641
IN	18,385,755	2,946,645	15,439,110	6,594,970	-8,844,140	52%	2,316	-2,594	3,351
MI	18,365,020	342,402	18,022,618	18,022,618	0	100%	6,790	0	6,919
MN	19,108,025	5,739,683	13,368,342	13,368,342	0	100%	4,204	0	6,009
MO	14,371,997	958,221	13,413,775	7,709,496	-5,704,280	60%	2,486	-1,673	2,795
ND	2,133,868	2,674,130	-540,262	12,764,834	13,305,095	100%	3,661	3,902	4,428
NE	4,746,550	540,133	4,206,417	16,028,858	11,822,441	100%	4,540	3,468	4,693
OH	28,314,777	18,641	28,296,135	14,148,068	-14,148,068	50%	5,313	-4,150	5,320
SD	1,900,439	1,019,244	881,196	12,491,757	11,610,562	100%	3,530	3,405	3,818
WI	15,574,889	1,500,588	14,074,301	6,011,979	-8,062,323	48%	2,288	-2,365	2,859
	166,553,235	30,290,346	136,262,889	136,262,540			45,357	0	55,164

A.17.3 2024 Low Wind Assumptions

- Wind energy requirements were based on the existing RPS mandates and goals shown Table A - 13.

- Power demand was assumed to be the same; however, energy growth was decreased from 1.0% to 0.3% to calculate the renewable energy requirement by state in 2024. This is shown in Table A - 18.

- The methodology for determining the wind nameplate capacity by state was similar to that adopted for the base case (Table 3-4 in the main report). The results are shown in Table A - 19.

Table A - 18: RPS Energy Requirement by State for Low Wind 2024

State	**IA**	**IL**	**IN**	**MI**	**MN**	**MO**	**ND**	**NE**	**OH**	**SD**	**WI**
State RPS Only	2%	23%	0%	10%	28%	15%	10%	15%	25%	10%	24%
% of energy renewable from wind (MWh)	80%	75%	80%	80%	80%	80%	80%	80%	50%	80%	65%
Average Capacity Factor (Supplied from Midwest ISO 3 Year Capacity Factor Statistics	0.378	0.3	0.325	0.303	0.363	0.354	0.398	0.403	0.304	0.404	0.3
High Wind State- yes/no? (High wind state if CF>36%)	Yes	No	No	No	Yes	No	Yes	Yes	No	Yes	No
Energy Growth (average US)	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%
Energy Usage by US State (MWh) / 2007 EIA	45,269,523	146,055,151	109,420,150	109,296,749	68,231,182	85,532,850	11,905,695	28,248,400	161,770,827	10,603,301	71,301,300
Total energy usage extrapolated assuming constant growth (MWh) (2029)	47,634,519	153,685,445	115,136,538	115,006,690	71,795,753	90,001,305	12,527,679	29,724,169	170,222,148	11,157,245	75,026,262
% for RPS renewable (MWh)	952,690	35,347,652	0	11,500,669	19,743,832	13,500,196	1,252,768	4,458,625	42,555,537	1,115,724	18,006,303
RPS energy from wind (MWh)	762,152	26,510,739	0	9,200,535	15,795,066	10,800,157	1,002,214	3,566,900	21,277,769	892,580	11,704,097
Total	101,512,209										

Table A - 19: Total Wind by State for Low Wind 2024

A	B	C	D	E	F	G	H	I	J
	Energy to meet ~80% RPS Requirement	Existing Wind	Incremental wind to meet ~80% RPS	Incremental Wind Prorate of NREL by State	Energy Import/Export by State	% RPS Wind Energy Generated In State	Incremental Wind Prorate of NREL by State	Import /Export by State	Total Wind by State Existing + Incremental
State	MWh	MWh	(B-C) MWh	MWh	(E-D) MWh	%	MW	MW	MW
IA	762,152	10,109,338	-9,347,186	6,012,713	15,359,899	100%	1,816	4,505	4,869
IL	26,510,739	4,441,320	22,069,419	8,105,436	-13,963,984	47%	3,084	-4,096	4,774
IN	0	2,946,645	0	0	0		0	0	1,035
MI	9,200,535	342,402	8,858,133	8,858,133	0	100%	3,337	0	3,466
MN	15,795,066	5,739,683	10,055,382	10,055,382	0	100%	3,162	0	4,967
MO	10,800,157	958,221	9,841,935	4,270,576	-5,571,359	48%	1,377	-1,634	1,686
ND	1,002,214	2,674,130	-1,671,916	7,070,915	8,742,831	100%	2,028	2,564	2,795
NE	3,566,900	540,133	3,026,767	8,878,980	5,852,212	100%	2,515	1,716	2,668
OH	21,277,769	18,641	21,259,127	10,629,564	-10,629,564	50%	3,992	-3,118	3,999
SD	892,580	1,019,244	-126,664	6,919,648	7,046,312	100%	1,955	2,067	2,243
WI	11,704,097	1,500,588	10,203,509	3,367,158	-6,836,351	42%	1,281	-2,005	1,852
	101,512,209	30,290,346	74,168,508	74,168,505			24,548	0	34,355

A.17.4 2019 Base Wind Assumptions

- Wind energy requirements were based on the RPS assumptions shown in Table A - 13.

- For each state in the study area, (except Wisconsin which used 1.1%), the usage was inflated by 1.0% annually through 2019. The 2019 state renewable energy requirements are shown in Table A - 20.

- The 2019 wind nameplate capacity by state was calculated using the same methodology as in the 2029 base case (Table 3-4 in the main report). The results are shown in Table A - 21.

Table A - 20: RPS Energy Requirement by State for Base Wind 2019

State	**IA**	**IL**	**IN**	**MI**	**MN**	**MO**	**ND**	**NE**	**OH**	**SD**	**WI**
Federal 20% - State RPS - Utility RPS in %	12.50%	16.00%	12.50%	12.50%	20.00%	12.50%	12.50%	12.50%	15.00%	12.50%	19.00%
% of energy renewable from wind (MWh)	80%	75%	80%	80%	80%	80%	80%	80%	50%	80%	65%
Average Capacity Factor (Supplied from Midwest ISO 3 Year Capacity Factor Statistics	0.378	0.3	0.325	0.303	0.363	0.354	0.398	0.403	0.304	0.404	0.3
High Wind State- yes/no? (High wind state if CF>36%)	Yes	No	No	No	Yes	No	Yes	Yes	No	Yes	No
Energy Growth (average US)	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.1%
Energy Usage by US State (MWh) / 2007 EIA	45,269,523	146,055,151	109,420,150	109,296,749	68,231,182	85,532,850	11,905,695	28,248,400	161,770,827	10,603,301	71,301,300
Total energy usage extrapolated assuming constant growth (MWh) (2019)	51,010,832	164,578,600	123,297,364	123,158,312	76,884,604	96,380,556	13,415,635	31,831,004	182,287,417	11,948,065	81,303,888
% for RPS renewable (MWh)	6,376,354	26,332,576	15,412,170	15,394,789	15,376,921	12,047,570	1,676,954	3,978,876	27,343,113	1,493,508	15,447,739
RPS energy from wind (MWh)	5,101,083	19,749,432	12,329,736	12,315,831	12,301,537	9,638,056	1,341,564	3,183,100	13,671,556	1,194,806	10,041,030
Total	100,867,732										

Table A - 21: Total Wind by State for Base Wind 2019

A	B	C	D	E	F	G	H	I	J
	Energy to meet ~80% RPS Requirement	**Existing Wind**	**Incremental wind to meet ~80% RPS**	**Incremental Wind Prorate of NREL by State**	**Energy Import/Export by State**	**% RPS Wind Energy Generated In State**	**Incremental Wind Prorate of NREL by State**	**Import/Export by State**	**Total Wind by State Existing + Incremental**
State	MWh	MWh	(B-C) MWh	MWh	(E-D) MWh	%	MW	MW	MW
IA	5,101,083	10,109,338	-5,008,255	5,440,234	10,448,489	100%	1,643	3,065	4,696
IL	19,749,432	4,441,320	15,308,112	7,347,894	-7,960,218	60%	2,796	-2,335	4,486
IN	12,329,736	2,946,645	9,383,091	4,120,772	-5,262,319	57%	1,447	-1,543	2,482
MI	12,315,831	342,402	11,973,429	11,973,429	0	100%	4,511	0	4,640
MN	12,301,537	5,739,683	6,561,853	6,561,853	0	100%	2,064	0	3,869
MO	9,638,056	958,221	8,679,834	3,863,968	-4,815,866	50%	1,246	-1,413	1,555
ND	1,341,564	2,674,130	-1,332,567	6,397,684	7,730,250	100%	1,835	2,267	2,602
NE	3,183,100	540,133	2,642,968	8,033,600	5,390,632	100%	2,276	1,581	2,429
OH	13,671,556	18,641	13,652,915	6,826,457	-6,826,457	50%	2,563	-2,002	2,570
SD	1,194,806	1,019,244	175,563	6,260,819	6,085,256	100%	1,769	1,785	2,057
WI	10,041,030	1,500,588	8,540,442	3,750,706	-4,789,736	52%	1,427	-1,405	1,998
	100,867,732	30,290,346	70,577,386	70,577,417			23,577	0	33,384

A.17.5 2019 High Wind Assumptions

- The 2019 renewable energy requirements for this scenario are based on the RPS requirements outlined in Table A - 13.

- Power demand was assumed to be the same; however, energy growth was increased from 1.0% to 2.0% to calculate the 2019 renewable energy required by state as shown in Table A - 22.

- The process for determining the wind nameplate capacity by state was similar to that used for the base cases (Table 3-4 in the main report). The results are shown in Table A - 23.

Table A - 22: RPS Energy Requirement by State for High Wind 2019

State	**IA**	**IL**	**IN**	**MI**	**MN**	**MO**	**ND**	**NE**	**OH**	**SD**	**WI**
Federal 20% - State RPS - Utility RPS in %	12.50%	16.00%	12.50%	12.50%	20.00%	12.50%	12.50%	12.50%	15.00%	12.50%	19.00%
% of energy renewable from wind (MWh)	80%	75%	80%	80%	80%	80%	80%	80%	50%	80%	65%
Average Capacity Factor (Supplied from Midwest ISO 3 Year Capacity Factor Statistics	0.378	0.3	0.325	0.303	0.363	0.354	0.398	0.403	0.304	0.404	0.3
High Wind State- yes/no? (high wind state if CF>36%)	Yes	No	No	No	Yes	No	Yes	Yes	No	Yes	No
Energy Growth (average US)	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%
Energy Usage by US State (MWh) / 2007 EIA	45,269,523	146,055,151	109,420,150	109,296,749	68,231,182	85,532,850	11,905,695	28,248,400	161,770,827	10,603,301	71,301,300
Total energy usage extrapolated assuming constant growth (billion MWh) (2029)	57,412,701	185,233,247	138,771,207	138,614,705	86,533,637	108,476,335	15,099,300	35,825,802	205,164,524	13,447,549	90,427,289
% for RPS renewable (MWh) - from Line 51*58	7,176,588	29,637,319	17,346,401	17,326,838	17,306,727	13,559,542	1,887,412	4,478,225	30,774,679	1,680,944	17,181,185
RPS energy from wind (MWh) - line 52*59	5,741,270	22,227,990	13,877,121	13,861,471	13,845,382	10,847,634	1,509,930	3,582,580	15,387,339	1,344,755	11,167,770
Total	113,393,241										

Table A - 23: Total Wind by State for High Wind 2019

A	B	C	D	E	F	G	H	I	J
	Energy to meet ~80% RPS Requirement	Existing Wind	Incremental wind to meet ~80% RPS	Incremental Wind Prorate of NREL by State	Energy Import/Export by State	% RPS Wind Energy Generated In State	Incremental Wind Prorate of NREL by State	Import/Export by State	Total Wind by State Existing + Incremental
State	MWh	MWh	(B-C) MWh	MWh	(E-D) MWh	%	MW	MW	MW
IA	5,741,270	10,109,338	-4,368,068	6,342,948	10,711,016	100%	1,916	3,142	4,969
IL	22,227,990	4,441,320	17,786,670	9,871,602	-7,915,068	64%	3,756	-2,322	5,446
IN	13,877,121	2,946,645	10,930,476	4,748,669	-6,181,807	55%	1,668	-1,813	2,703
MI	13,861,471	342,402	13,519,068	13,519,068	0	100%	5,093	0	5,222
MN	13,845,382	5,739,683	8,105,698	8,105,698	0	100%	2,549	0	4,354
MO	10,847,634	958,221	9,889,412	4,505,128	-5,384,284	50%	1,453	-1,579	1,762
ND	1,509,930	2,674,130	-1,164,200	7,459,269	8,623,470	100%	2,139	2,529	2,906
NE	3,582,580	540,133	3,042,447	9,366,638	6,324,190	100%	2,653	1,855	2,806
OH	15,387,339	18,641	15,368,698	7,684,349	-7,684,349	50%	2,886	-2,254	2,893
SD	1,344,755	1,019,244	325,511	7,299,694	6,974,183	100%	2,063	2,046	2,351
WI	11,167,770	1,500,588	9,667,182	4,199,840	-5,467,343	51%	1,598	-1,604	2,169
	113,393,241	30,290,346	83,102,895	83,102,903			27,774	0	37,581

A.17.6 2019 Low Wind Assumptions

- The 2019 renewable energy requirements for this scenario are based on existing state RPS requirements shown in Table A - 13.

- Power demand was assumed to be the same; however, energy growth was decreased from 1.0% to 0.3% to calculate the 2019 renewable energy requirement by state. This is shown in Table A - 24.

- The methodology for determining the wind nameplate capacity by state was similar to that adopted for the base case (Table 3-4 in the main report). The results are shown in Table A - 25.

Table A - 24: RPS Energy Requirement by State for Low Wind 2019

State	IA	IL	IN	MI	MN	MO	ND	NE	OH	SD	WI
State RPS Only	2%	16%	0%	10%	25%	13%	10%	13%	15%	10%	19%
% of energy renewable from wind (MWh)	80%	75%	80%	80%	80%	80%	80%	80%	50%	80%	65%
Average Capacity Factor (Supplied from Midwest ISO 3 Year Capacity Factor Statistics	0.378	0.3	0.325	0.303	0.363	0.354	0.398	0.403	0.304	0.404	0.3
High Wind State- yes/no? (High wind state if CF>36%)	Yes	No	No	No	Yes	No	Yes	Yes	No	Yes	No
Energy Growth (average US)	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%
Energy Usage by US State (MWh) / 2007 EIA	45,269,523	146,055,151	109,420,150	109,296,749	68,231,182	85,532,850	11,905,695	28,248,400	161,770,827	10,603,301	71,301,300
Total energy usage extrapolated assuming constant growth (MWh) (2029)	46,926,387	151,400,767	113,424,925	113,297,008	70,728,442	88,663,351	12,341,443	29,282,291	167,691,636	10,991,382	73,910,926
% for RPS renewable (MWh)	938,528	24,224,123	0	11,329,701	17,682,110	11,082,919	1,234,144	3,660,286	25,153,745	1,099,138	14,043,076
RPS energy from wind (MWh)	750,822	18,168,092	0	9,063,761	14,145,688	8,866,335	987,315	2,928,229	12,576,873	879,311	9,127,999
Total	77,494,425										

Table A - 25: Total Wind by State for Low Wind 2019

A	B	C	D	E	F	G	H	I	J
	Energy to meet ~80% RPS Requirement	**Existing Wind**	**Incremental wind to meet ~80% RPS**	**Incremental Wind Prorate of NREL by State**	**Energy Import/Export by State**	**% RPS Wind Energy Generated In State**	**Incremental Wind Prorate of NREL by State**	**Import/Export by State**	**Total Wind by State Existing + Incremental**
State	**MWh**	**MWh**	**(B-C) MWh**	**MWh**	**(E-D) MWh**	**%**	**MW**	**MW**	**MW**
IA	750,822	10,109,338	-9,358,516	3,472,628	12,831,143	100%	1,049	3,763	4,102
IL	18,168,092	4,441,320	13,726,772	4,667,102	-9,059,670	50%	1,776	-2,657	3,466
IN	0	2,946,645	0	0	0		0	0	1,035
MI	9,063,761	342,402	8,721,359	8,721,359	0	100%	3,286	0	3,415
MN	14,145,688	5,739,683	8,406,005	8,406,005	0	100%	2,643	0	4,448
MO	8,866,335	958,221	7,908,114	2,466,461	-5,441,653	39%	795	-1,596	1,104
ND	987,315	2,674,130	-1,686,815	4,083,790	5,770,604	100%	1,171	1,693	1,938
NE	2,928,229	540,133	2,388,096	5,128,033	2,739,937	100%	1,453	804	1,606
OH	12,576,873	18,641	12,558,231	6,279,116	-6,279,116	50%	2,358	-1,842	2,365
SD	879,311	1,019,244	-139,933	3,996,426	4,136,359	100%	1,129	1,213	1,417
WI	9,127,999	1,500,588	7,627,411	2,929,803	-4,697,608	49%	1,115	-1,378	1,686
	77,494,425	30,290,346	50,150,725	50,150,721			16,775	0	26,582

B Appendix B: Study Methodology

B.1 Futures

B.1.1 Base Case

Based on the key assumptions detailed in Appendix A, 2029 on and off peak cases were developed. The wind energy calculations were based on 1.0% annual energy growth and the Renewable Portfolio Standard (RPS) requirements as shown in Table 3-1 of the main report. The methodologies used to develop the wind generation capacity by state for the 2029 base case are discussed in Section 3 of the main body of the report

The transmission alternatives were designed to meet the performance criteria under base case assumptions. In addition to the 2029 base cases, two generation future cases were created to evaluate the robustness of the alternatives. Futures analysis takes into account the uncertainties surrounding public policy and economic drivers that may impact the generation portfolio. The alternatives were tested under High Gas and Low Carbon Future scenarios.

B.1.2 High Gas Future

The High Gas Future assumes that gas will be the preferred technology for new generation development. This Future was included due to its smaller environmental footprint as compared to other fossil fuels, its flexibility in terms of use, and shorter plant construction timeframe. The following adjustments were made to the on and off peak base cases to develop corresponding high gas future cases.

- Wind generation used to develop the high gas future cases remained the same as the base cases.
- An additional 11.6 GW of gas generation was added.
- Existing coal units were reduced to accommodate the additional gas unit generation.

B.1.3 Low Carbon Future

The Low Carbon Future is based on the premise of reducing the output of carbon emitting generation resources. The following adjustments were made to the on and off peak base cases to develop corresponding low carbon future cases.

- The wind generation used for developing the low carbon future cases was the same as for the base cases.
- Approximately 1 GW of hydro power was added.
- Approximately 1 GW of nuclear generation was added.
- Approximately 4 GW of gas generation was added.
- Approximately 2 GW of wind generation was added in North and South Dakota and Minnesota.
- Approximately 3 GW of wind generation was imported from SPP
- Coal units with maximum nameplate ratings of 250 MW that were 40 years or older in 2010 were retired. This resulted in a reduction of 2 GW of coal generation.

- The remaining 9 GW was accounted for by reducing the output of existing coal units.

B.2 Sensitivities

To test the alternatives for robustness under specific conditions, sensitivities were run for generation and load cases. Generation cases were run for the off peak base cases. Load cases were run for the on peak base cases.

B.2.1 High Wind

The high wind generation sensitivity was designed to address the higher than expected energy usage that would be associated with economic growth during the 20-year period. For this sensitivity, the renewable requirements were based on 2.0% energy growth as opposed to the 1.0% assumed in the base case. This equates to a need for an additional 13 GW of nameplate wind generation. Table A - 9 and Table A - 10 in Appendix A show the calculations for the wind nameplate values by state. The high wind generation sensitivity was applied to the off peak base and futures cases. The low demand levels and high wind generation availability during off peak hours result in high loading on the transmission facilities. The off peak case was therefore considered as an appropriate measure for robustness. To account for the excess wind generation, the models simulated energy transfers by creating load sinks (~8.4GW) along the eastern border of AEP's service territory.

B.2.2 Low Wind

The low wind generation sensitivity was designed to address uncertainties surrounding renewable energy polices and take into account lower than anticipated energy growth during the 20-year study period. Renewable requirements were based on existing RPS requirements (Table 3-1 in the main report) and energy growth of 0.3% as opposed to 1.0% in the base case.

Table A - 12 calculates the wind nameplate values by state that result in a total reduction of 20 GW wind power.

B.2.3 High Wind Import from SPP

Given the significant wind activity in SPP, this sensitivity provides insight into the contribution of the SPP wind generation to the eastern market. Approximately, 3 GW of wind imports from the SPP region were modeled in the off peak case. To account for the imports, the models simulated energy transfers by creating load sinks along the eastern border of AEP's service territory. The Study applied this sensitivity to the off peak cases due to high wind availability during off peak hours. The SPP imports result in increased west to east line loading levels on the transmission overlays.

B.2.4 Higher than forecasted load growth

This sensitivity tests for stronger than anticipated economic growth during the 20 year period. The load levels in the base and future on peak cases were increased by 1.0% for all the control areas. This resulted in 2 GW of additional load as compared to the base case.

B.2.5 Lower than forecasted load growth

This sensitivity was designed to test the impact of increased energy efficiency, demand side management and weak economic growth. The load levels in the base and Future on peak cases were decreased by 5% for the control areas. This resulted in a load reduction of 8 GW as compared to the base case.

B.3 2019 and 2024 Analysis

After the 2029 EHV Overlay alternatives were defined, transmission upgrade requirements for 2024 and 2019 were developed. This sequencing process was used to facilitate an efficient build out of the transmission overlay in an effort to preclude the development of a piecemeal transmission system that only considers immediate needs. The overlays were sensitivity tested for high and low wind, higher than forecasted load growth, and SPP Imports.