DAKOTAS WIND TRANSMISSION STUDY

STUDY SUMMARY

TASK 1 THROUGH TASK 4

Prepared for:

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Technical Report

Dakotas Wind Transmission Study	No. 2005-10977-4 R1		
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Summary:

ABB Inc. was contracted to perform a Dakotas Wind Transmission Study for investigating transmission capacity for up to 500 MW of total new wind generation to be located at seven proposed sites. This report summarizes the results for Task 1 through Task 4 of the Dakotas Wind Transmission Study. Chronologically, the Study proceeded with work performed on Task 1 first, followed by study work on Task 3 (based on the dependency of Task 3 results being a prerequisite to Task 4) and completed with study work with Task 2 and Task 4.

TASK 1

Task 1 of the study took the actual system load, generation, and power transfers for the year 2003 and developed a database utilizing ABB GridView software. The GridView software simulated a powerflow for each hour of 2003 year and was benchmarked against the actual measured interface flows for three critical interfaces in the Dakotas. Based on the weather data for 2003, the expected wind generation that could have been generated each hour of 2003 at each of the seven sites was calculated. This data, along with data provided by Western for the 2003 year, was put into a database for the GridView software that simulated a powerflow for each hour of year 2003 with wind generation at one of the seven sites. GridView monitored the transfer limits and identified those hours that transmission capacity was not available to transmit the wind energy being generated. The results included the level of wind generation that cannot be delivered during periods the transmission system constrains the power transfers. These steps were also repeated for a high hydro year since 2003 was a low hydro year.

The seven wind sites and the three system interfaces considered in Task 1 are identified in Figures 1 and 2 below.

Figure 1 – Identified area around:

Garrison, N.D.
Pickert, N.D.
Ellendale, N.D.
New Underwood, S.D
Ft. Thompson, S.D.
Mission, S.D.
Near White Substation, S.D

Figure 2 – Three Transmission Interface Considerations: 1) Boundary stretching across northern South Dakota through eastern Minnesota, back through northern North Dakota; 2) Boundary are lines extending east from White Substation area, eastern South Dakota; 3) Boundary lines east out of Ft. Thompson, South Dakota area.

Note: For security reasons the maps of Figure 1 and 2 of this report on page 3 are not posted on the web and any questions should be directed to Sam Miller (406-247-7466, csmiller@wapa.gov) or Ed Weber (406-247-7433, weber@wapa.gov).

The results and major conclusions from Task 1 are:

1. The wind generation at each of the seven sites was predicted for the year 2003. The generation at each site varies from minimum to maximum throughout the year and indicates an average annual capacity factor at each site around 40%.
2. Benchmark cases for each interface were simulated with GridView and compared to the metered data for 2003. The NDEX and Ft. Thompson interface flows closely correlate between GridView and the measured values. The Watertown interface was not as closely correlated due to its interdependency on Big Stone generation levels. Big Stone generation data was not available.
3. GridView simulations were completed for the historical year 2003 and for a high hydro year for the wind generation at each site.
4. For the year 2003, NDEX transfers were above the NDEX limit for the three North Dakota sites for only a few hours each year. The results are similar for the high hydro year.
   - NDEX was exceeded most with wind at the Garrison site. For 2003 simulations the NDEX limit was exceeded for 14 hours with 849 MWH undelivered during the year and for the high hydro simulations NDEX was exceeded for 32 hours with 2256 MWH undelivered during the year. For either case this is less than 0.1% of the energy generated at the Garrison site by the wind.
   - No overloads were seen on the other interfaces with the wind generation.

The main conclusion from Task 1 is that under normal system intact conditions, non-firm transmission is available most of the time across the three monitored interfaces for up to 500 MW of new wind generation at any one of the seven wind sites studied.

TASK 3 AND TASK 4

Task 3 is the interconnection studies for each of the seven sites. This task determined the local system requirements to connect the proposed wind generation to the existing system and identified any local enhancements needed to accommodate the new generation. Task 4 analyzed the transfer capability to ship power from the wind sites to markets. Regional stability performance and limitations were also analyzed and where limitations existed the study evaluated the potential for some transmission technologies such as FACTS to increase the transfer of power from the Dakotas.

The seven wind generation sites in North and South Dakota were assumed to be connected to the following substations and buses: Garrison 230 kV, Pickert 230 kV, Ellendale (a new 345-kV tap on the Leland Olds-Groton line), New Underwood 230 kV, Mission 115 kV, Ft. Thompson 345 kV, and White 345 kV. These sites are shown in Figure 1.

System Criteria

In the steady-state analysis, Rate B in the database was used for determining the transmission branch loadings. Rate B for transmission lines is the continuous rating of the line without considering limitations of substation equipment. In the stability analysis, 6-cycle faults were simulated for local faults unless the faults were on the 345-kV system and the results were

unstable. For those cases the simulations were rerun with 4-cycle faults. Regional stability was analyzed using the MAPP UIP package and modeled for summer off-peak 2003 condition with maximum simultaneous NDEX (≈1950MW), MHEX (≈2175MW), and MWSI (≈1480MW) transfers. These transfer limits were based on the system data as established by MAPP in November 2004.

Tasks 3 and 4 Conclusions

Task 1 results indicated that for 500 MW installed at any one of the seven sites, there was non-firm transmission capacity across the critical interfaces to transfer almost all of the wind energy. Tasks 3 and 4 show some limitations in this non-firm capacity. Due to thermal limits, stability limits, and security considerations some of the sites are limited to less than 500 MW without additional system enhancements.

The table below contains an overall summary of the level of generation at each site that can be transferred as non-firm power based on the various system limitations. Some system enhancements are also added to increase these transfers.

Table 1 Non-Firm Transfer Capacity with Various System Limitations

NON-FIRM TRANSMISSION SYSTEM STUDY RESULTS							
	EXISTING SYSTEM THERMAL LIMIT	SYSTEM WITH NEW LOCAL LINES	LOCAL STABILITY	REGIONAL STABILITY NORMAL SYSTEM	REGIONAL STABILITY WITH 35% SERIES COMP	DYNAMIC UNDERVOLTAGES NORMAL SYSTEM	DYNAMIC UNDERVOLTAGES WITH SVCS
Garrison	500		500	250	500	150	500
Pickert	500		500	500		500	
Ellendale	500		500	250	500	150	500
New Underwood	500		500	500			500
Mission	250	500	500	375		500	
Ft. Thompson	500		500	500		500	
White	500		500	500		500	
SITES 1-7	500		500	500		500	

In the steady-state analysis for normal system conditions and for the N-1 contingency analysis, there were only a few overloaded transmission lines. For N-1 contingencies, there were two outages. The steady-state analysis is summarized as follows:

- The Mission site can only support 250 MW with the existing transmission. Two new 230-kV lines will support 500 MW out of the Mission site.
- There are two sites with the normal system conditions which load one line to between 100-105%
- There are only a few contingencies that overload transmission lines.
- Most of the transformer overloads are also in the base case except for the New Underwood site which overloads the existing transformer at New Underwood
- Most of the wind sites showed results where a few locations demonstrated low voltages in central North Dakota that will need shunt capacitor support to maintain the system voltage.

Those cases with one or two lines loaded between 100 and 110% were listed as OK in Table 1. Alternatives for relieving these overloads were addressed in Task 2.

All sites provided good performance for the local stability analysis.

For the regional stability study, non-firm and firm transfer cases were set up based on the exports on the NDEX interface. Non-firm assumes that NDEX is 1450 MW with 500 MW of non-firm transfer capacity available on the systems. Firm assumes that NDEX is 1950 MW before wind generation from 50 MW to 500 MW is added.

The following are the conclusions for the regional stability analysis on the non-firm transfer cases:

For the eight scenarios using non-firm transmission, NDEX was readjusted to maintain a 1450 MW export leaving 500 MW for non-firm transfers. The maximum wind generation of 500 MW was added to a wind site and the regional stability simulations were run. The results of the regional stability are as listed below:

Garrison 230 kV	250 MW
Pickert 230 kV	500 MW
Ellendale 345 kV	250 MW
New Underwood 230 kV	500 MW
Mission 115 kV	375 MW
Ft. Thompson 345 kV	500 MW
White 345 kV	500 MW
Scenario 8, All Sites	500 MW

The Garrison and Ellendale sites had some incremental degradation of voltages in the locations of Groton and Granite Falls for the levels of generation listed above. A 200 MVAr SVC was modeled at Groton for these two sites and the voltage performance met the criteria with the SVC. Low voltages in the New Underwood area during regional disturbances when wind generation is connected at New Underwood would also require some dynamic voltage support.

The following are the conclusions for the regional stability analysis on the firm transfer cases:

These are the results with NDEX at 1950 MW for the regional stability cases without any enhancements to the network, then new wind generation is added for each site, and evaluated. If the wind generation is added to the existing firm commitments, the following generation can be added at each site without system enhancement to improve inter-regional transfers.

Garrison 230 kV	50 MW
Pickert 230 kV	50 MW
Ellendale 345 kV	50 MW
New Underwood 230 kV	50 MW
Mission 115 kV	150 MW
Ft. Thompson 345 kV	50 MW
White 345 kV	250 MW

Series compensation of 35% of the line reactance in the Leland Olds-Groton 345-kV line, the Leland Olds-Ft. Thompson 345-kV line, and the Antelope Valley-Broadland 345-kV line for the non-firm and the firm transfer cases will raise the stability interconnection capacity of each site as follows:

Results of 35% series compensation on non-firm transfer cases:

Garrison 230 kV	500 MW
Ellendale 345 kV	500 MW

Results of 35% series compensation on firm transfer cases:

New Underwood 230kV	150 MW
Mission 115kV	250 MW
Ft. Thompson 345kV	150 MW
White 345kV	375 MW
Case 8	500 MW

Series compensation of 50% of the line reactance in the Leland Olds-Groton 345-kV line, the Leland Olds-Ft. Thompson 345-kV line, and the Antelope Valley-Broadland 345-kV line was tested for two sites and will raise the interconnection capacity of the following two sites:

Results of 50% series compensation on firm transfer cases:

Ft. Thompson 345kV	250 MW
White 345kV	500 MW

The series capacitor compensation was only tested for improving the stability. A complete analysis of this technology needs to include steady-state contingency analysis, stability, and special studies such as sub-synchronous resonance (SSR). These cases demonstrate the improved performance due to additional technologies that can be implemented to help eliminate system constraints. Further fine-tuning is required for the above values to design actual values, based on site selection.

A system upgrade case was developed by adding a new 345-kV transmission line from Maple River to Benton County for all the interconnection sites except for the interconnection at Mission. The results of the stability cases are indicated below.

Results of New Maple River-Benton County 345-kV Line on firm transfer cases:

Garrison 230 kV	375 MW
Ellendale 345 kV	500 MW
White 345kV	500 MW

Two new 230-kV lines were modeled connecting Mission to the Oahe and Ft. Randal Substation. With these two new lines, the steady-state performance indicated that 500 MW of wind could be accommodated, but the stability limits for inter-regional stability remain the same as reported above.

These cases demonstrate the improved performance due to additional technologies that can be implemented to help eliminate system constraints. Further fine-tuning is required for the above values to design actual values, based on site selection.

Additional sensitivity of new transmission lines on the firm transfer cases were performed by adding new transmission lines in the system to increase the power transfers. For NDEX set to 1950 MW before the wind generation is connected, 375 MW of additional generation can be interconnected at Garrison and 500 MW can be connected at the Ellendale and White sites without degrading the inter-regional transfers.

TASK 2

Task 2 provides an overview of some of the transmission technologies to mitigate overloads and stability problems without adding new transmission lines to the system. The results of the Task 3 and 4 studies indicated some steady-state and dynamic stability problems when wind generation was added. For two of the sites there were some possible transmission line overloads following a contingency. Overloads at these two sites could potentially be resolved by using dynamic rating of the lines.

Under some system export conditions there were some system instability and low dynamic voltage problems. Simulations of series capacitor compensation and SVC demonstrated how these technologies could improve the system performance for these dynamic problems.

Task 2 reviewed various methodologies available to mitigate some of the system problems identified in the Task 3 and 4 studies. The technologies considered in this
Task included the following:

- Re-conductor transmission lines
- Dynamic transmission line ratings
- Add conventional series capacitors
- Add controllable series capacitors
- Add SVCs or STATCOMs
- Add phase shifting transformers

For the steady-state overloading problems, the dynamic transmission line rating and re-conductoring the transmission lines can mitigate the problems. For the dynamic instability and low voltage problems, series capacitors and SVCs or STATCOMs can improve the system performance.

For the Pickard and Mission site, the overloads on the lines were modest indicating that dynamic thermal ratings of the lines was the most promising economical solution. Some of the wind generation sites that were unstable following the faults with just the existing system were rerun with 35% and 50% of series compensation on the Leland Olds-Groton 345-kV line, Leland Olds-Ft. Thompson 345-kV line, and Antelope Valley-Broadland 500-kV line (operating at 345 kV). Series compensation increases the level of wind generation that can be exported. Three

of the site had some low voltages for inter-regional stability disturbances. A 200 MVAr SVC was modeled and it eliminated the low voltages in the Groton area for those cases that had low voltages. These technologies were presented in detail in Task 2.