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The Way to a TransCanada Electric Transmission System

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SUMMARY

A TransCanada electric transmission system is presented as an essential way forward to reduce thermal electric generation and increase renewable energy integration. To meet this national objective, the TransCanada electric grid must be profitable. It is not possible today to economically justify the cost of the grid just on differential electricity energy prices. As each interconnected province retires thermal generators and as its load grows, reserve margins (total capacity greater than peak load) can be reduced while maintaining the same degree of reliability. The TransCanada grid would thus delay the need for new replacement generation. Some of the saving can be allocated to help pay it off.

Greater benefits can be achieved for the TransCanada grid if it is integrated with a potential overlaying electric grid in the USA. This benefit was shown by a recently completed Pan-Canadian Wind Integration Study (PCWIS), co-funded by Natural Resources Canada (NRCan) through the ecoEnergy Innovation Initiative (ecoEII) and the Canadian Wind Energy Association (CanWEA). This study determined the size of inter-area transmission reinforcements that would be required to accommodate the increased levels of wind generation in order to limit energy curtailment and keep transmission congestion at reasonable levels. Studies to determine the benefits for wind integration with additional interconnections between provinces and to states in the USA include production cost studies, reliability and capacity adequacy studies and grid stability studies. These are challenging studies requiring a great deal of data.

The overall objective in extending these studies for a TransCanada grid is to demonstrate an acceptable benefit to cost ratio of 1.25. With proven profitability, private and public funding will be attracted. There are remaining challenges to a TransCanada grid. Foremost is the required cooperation between the provinces (and states). Secondly, social acceptances of new high power overhead transmission lines are required to limit use of expensive underground cables; otherwise line permitting may be delayed. Hence low profile, aesthetic appearing transmission strategically routed is the best hope of implementing the TransCanada grid for social acceptance at minimized cost.

KEYWORDS

HVDC transmission lines, Interconnections, TransCanada electric grid, Transcontinental electric grid, Wind integration, Renewable energy, Energy storage, Macrogrid

1. BACKGROUND

A TransCanada electric transmission system with increased interprovincial interconnection capacity will be emblematic of Canada's national railways and the TransCanada highway. Its concept has long been contemplated. A recent proposal [1] recommended an incremental approach by establishing regional hubs that link existing and future renewable projects to major load centres. By contrast, this paper recommends staging with the western provinces being one stage, the eastern provinces being another stage and a third stage interconnecting the west to the east through Ontario and the USA. By interconnecting the TransCanada electric transmission system with a USA overlaying transmission system, it is possible both can be self-contingent. The major benefit of self-contingency is that loss of one section of the overlaying transmission system would minimally disturb the existing underlying AC transmission system's design features.

Cost is always the concern. Strong emphasis is made that the overlaying TransCanada electric transmission system must be profitable. When so demonstrated by very detailed study and analysis, it will be evident that public and private investments will receive positive returns. To achieve this, all provinces and the federal government must find a way to cooperate with power system planning. This is probably the greatest challenge to reaching a TransCanada electric transmission system and its resulting and significant energy and environmental benefits.

The following sections outline a way forward to achieve a profitable TransCanada electric transmission system that will be a significant contribution to Canada's climate change objectives.

2. THE TRANSCANADA GRID MUST BE PROFITABLE

Pioneering work has been undertaken in recent years by the Mid-continent Independent System Operator (MISO) in evaluating the potential economic benefits of a USA overlay grid now termed a "Macro Grid" [2]. The economic benefits of the macro grid determined by MISO can be directly applied to the TransCanada grid, particularly if it is integrated with a future macro grid in the USA. These benefits are derived from:

I. Overall reduced generation requirements to maintain the same or improved system reliability, increased capacity sharing and reduced spinning and margin reserves. As each interconnected province retires thermal generators and as its load grows, margins can be reduced maintaining the same degree of reliability and so new replacement generation need not be purchased and some of the saving can be allocated to help pay for the TransCanada Grid. This can be the major cost benefit to the TransCanada grid

II. Increased and dependable use of wind and solar generation contributing to growth in the new economy. With wide area transmission, intermittent energy generation is firmed up

III. Smooth out the adverse impact of sudden weather changes on solar and wind energy generation

IV. The use of direct current transmission to remove the difficulties of maintaining a synchronous operation in alternating current over a wide area and provide frequency stabilization benefits

V. Obtaining benefits from time zone and climatic differences across the country to take advantage of the diversity from daily and seasonal regional peak loads that will occur at different instances of time;

VI. A larger more integrated area-wide electric energy market would be established

VII. The use of hydroelectricity in Quebec, Manitoba and BC and pumped storage facilities, could be utilized as bulk energy storage, providing a balancing capability for the increasing variable renewable energy of solar and wind generators; and

VIII. Provide added security to Canadian electric utilities and “black start” ability if a province suffers is own wide area blackout

One concept of a combined Canada and USA transcontinental overlaying electric grid is presented in Figure 1. The USA portion is mostly derived from the macro grid of MISO [2]. The portion from Ontario to BC can be designed and controlled to be self-contingent. For example it the line section from Winnipeg to Regina trips out, the power into or out of both cities can be quickly restored through the parallel paths of the overlaying grid with minimal impact on the underlying AC network. Further development is required from Ontario east to the Maritimes to increase self-contingency.

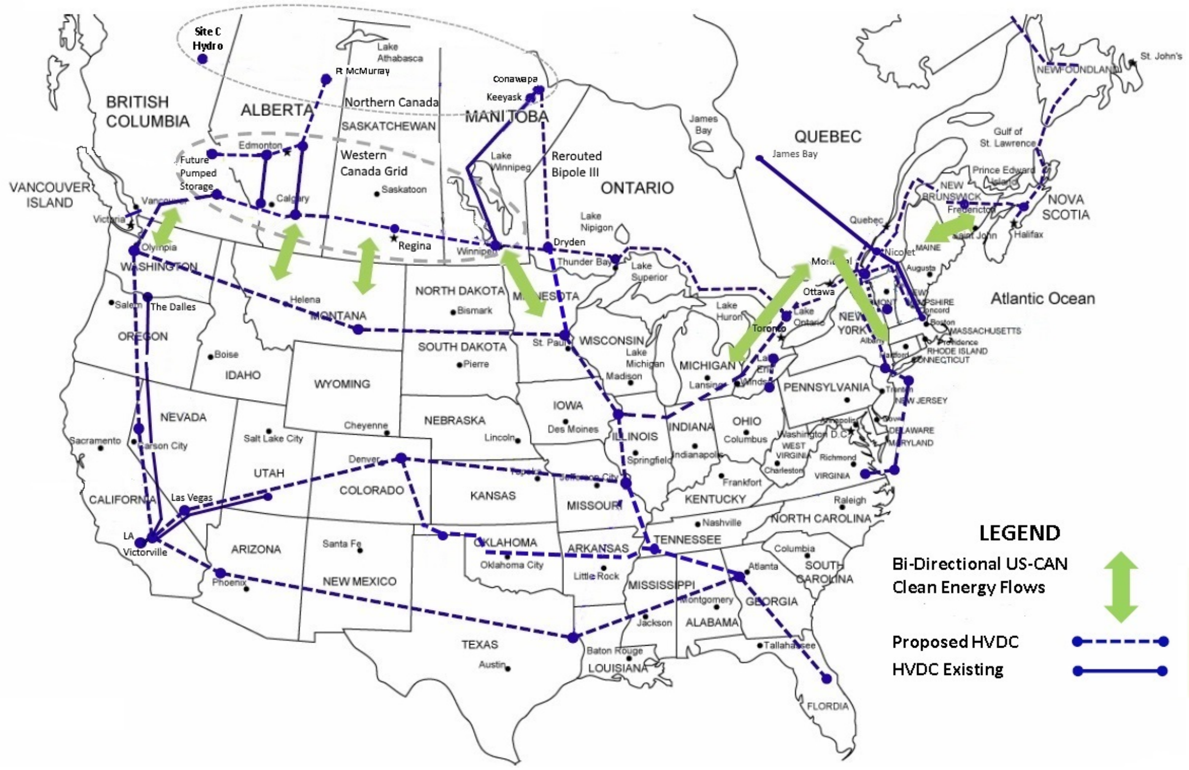

Figure 1: One concept of a combined Canada and USA transcontiental overlaying grid

For the USA portion of their macro grid, MISO has determined $US50 billion total potential benefits [2] that include:

- 30 GW of displaced peaking generation
- 30 GW capability to firm and deliver renewable energy from a wide area
- Frequency stabilization in segmented systems (WECC, ERCOT, Eastern Interconnect)

The cost of the USA portion of their macro grid was estimated to be $36 billion producing a benefit to cost ratio of 1.25. These and other benefits could similarly apply for the TransCanada grid. With a significant benefit derived from displaced peaking generation and margin reduction, the actual power flow through the transmission is needed only occasionally. This leaves unused capacity for energy arbitrage across a wide market and for integration of renewable energy along with other benefits.

3. THE PCWIS IS A START

One portion of the benefits for increased transmission between the provinces and the USA has been recently investigated through the Pan-Canadian Wind Integration Study (PCWIS)[1] which was performed to assess the implications of integrating large amounts of wind in the Canadian electrical system [3]. The study aimed to develop an understanding of the operational implications of how variable wind energy resources would affect the existing and future electricity grid, and what environmental and economic costs and benefits may be associated with integrating large amounts of wind energy in Canada.

The study utilized the GE MAPS models to simulate unit commitments and economic dispatch in North America covering both Canada and USA. Reliability analysis was performed using GE MARS model. PCWIS considered four base case scenarios of wind penetration in 2025 in Canada from 5% to 35% wind penetration.

The percent wind penetration refers to the percentage of annual electric generation provided by the wind resources in Canada. The study findings indicate that the Canadian power system, with adequate transmission reinforcements and additional regulating reserves, will not have any significant operational issues operating with 20% or 35% of its energy provided by wind generation. The 35% wind penetration was the highest wind penetration scenario considered but is not necessarily the upper limit on reliable wind penetration in Canada.

Canada has high quality wind resources in all provinces, with simulated average capacity factors ranging 34% in British Columbia to 40% in Nova Scotia. The study results indicate that there is no significant advantage to concentrate wind resources in provinces with slightly higher wind capacity factors. Instead, it is more beneficial to add the wind generation in regions where the energy can be partially used within the province and partially shared with neighbouring provinces and USA states.

The study shows that additional wind energy displaces more expensive gas and coal-fired generation in both Canada and the USA, with about half of the total displacement occurred in Canada, resulting in economic benefits for the Canadian systems. Furthermore, displacement of conventional generation results in corresponding reduction in criteria pollutants (i.e., SO_X and NO_X), and greenhouse gases (i.e., CO_2) in both Canada and USA.

The study determined the size of inter-area transmission reinforcements that would be required to accommodate the increased levels of wind generation in order to limit energy curtailment and keep transmission congestion at reasonable levels.

The 20% scenarios require 4.6 to 4.8 GW of new inter-area transfer capacity with a total estimated cost of C$2.7 billion. The 35% scenario requires about 10 GW of new transfer capacity with an estimated cost of C$3.7billion. Production simulation results show that operating cost savings in all of North America (USA and Canada) from these transmission reinforcements is C$565M, indicating an approximate investment payback period of 4 years in the 5% scenario and 3 years in the 35% scenario. This is an approximate straight line payback analysis, with interest, financing costs, etc. not taken into account.

The production cost analysis shows that wind energy has a value (avoided cost) of about C$43.4/megawatt hour (MWh) in a 20% scenario and about C$40.5/MWh in the 35% scenario. Recent projects in North America at sites with similar capacity factors have been developed with levelized

[1] PCWIS was co-funded by Natural Resources Canada (NRCan) through the ecoEnergy Innovation Initiative (ecoEII) and the Canadian Wind Energy Association (CanWEA). PCWIS project team consisted of GE Energy Consulting (as project manager), Electranix, Vaisala, EnerNex, and Knight Piésold, with advice and review provided by a Technical Advisory Committee consisting of power system representatives from Canada and USA, and DNV GL acting as project advisor to CanWEA

cost of energy (LCOE) in that same range. This indicates that the wind energy postulated in the study scenarios is very likely to be economically feasible.

With the transmission reinforcements, there is only a modest amount of curtailed energy in the study scenarios: about 6.5% to 6.9% energy curtailment with 20% wind penetration, and 11% energy curtailment in 35% wind penetration in Canada.

The reductions in production cost are in both Canadian and USA operating areas, and about half of the transmission reinforcements are between Canada and the USA. Implementing such projects would necessarily involve entities from both sides of the US-Canada border, as multiple entities would share costs and benefits.

The results show that utilization of the ties is relatively small. It is at full capacity only a few hours of the year. Utilization increases somewhat with increased wind penetration. Production cost results indicate that the Eastern and Western grids have similar operating costs and similar operating patterns, with only occasional opportunities to economically exchange energy. Therefore, modeling the Eastern and Western Interconnections separately for this study does not significantly affect the results. The benefits from increased wind penetration with the TransCanada grid will require a full analysis.

4. SOCIALLY ACCEPTABLE TRANSMISSION

While the benefits of the TransCanada grid are recognized in this paper, one of the main challenges today with overhead high voltage transmission implementation is achieving social and environmental acceptance. On the other hand, underground cables cost four to fifteen times more than an overhead line depending on the voltage level and the line route.

The majority of existing transmission towers is of the lattice type design which has changed little over the past hundred years. This is important since public opposition to additional power transmission lines is apparently much more related to appearance than other factors. The public perception of lattice towers is that they are as a symbol of blemish that overhead lines are imposing on natural landscapes. European experience has shown low profile aesthetic designs can improve the prospect of lessened visual impact and increase public acceptance. Their reduced right-of-way (ROW) increases the likelihood that new circuits can share existing ROW with transportation corridors and other transmission lines, and lessening environmental impact [4]. The greater lengths of overhead transmission possible with social acceptance, the less underground transmission will be required minimizing overall transmission costs. Figure 2 shows conventional and compact low profile HVDC transmission.

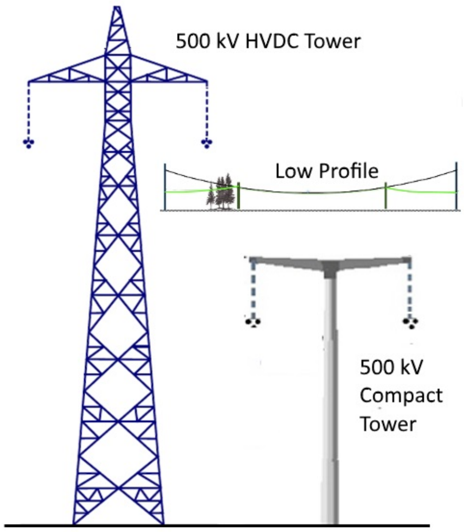

Figure 2 Comparison of Compact and lattice towers

5. STUDIES REQUIRED TO MOVE FORWARD

A TransCanada electric transmission system with increased interprovincial interconnection capacity would yield benefits across many facets of Canada's power and energy sectors. As listed in Section 2 above, it would yield economic benefits and increased operational efficiency by sharing generating assets across provincial boundaries. It would allow renewable energy from wind and solar to be transported across large distances, spanning across weather patterns and time zones, thus firming them up where locally are considered non-firm. A TransCanada grid would also span several climates, allowing a diversified peak load pattern yielding significant capacity benefits delaying the need for large capital investments in new generating assets. Finally, a TransCanada grid would yield grid stability and reliability benefits during emergency events, allowing generators in one province to respond to contingency events in another province within seconds while diversifying and expanding the system's reserves.

However, a broad TransCanada electric transmission system would increase engineering complexity. Resource optimization would span an expansive generating fleet and customer loads across four time zones. Grid stability would need to be maintained across multiple balancing areas. As a result, detailed power system studies are required to improve our engineering knowledge across a complex system, to quantify the benefits of increased operational efficiency and load diversification, and ensure an investment of this magnitude would be prudent even with future uncertainties.

Fortunately, there are a variety of power system tools and modelling techniques that can be leveraged to perform these studies. While the analytical tools and methods outlined below are divided into three disciplines, a study of this magnitude would require a cohesive modelling approach, combining each analysis into a unified study. The following analysis cannot be done independently or in isolation because there are critical feedback loops between the different stages of power system planning. Figure 3 provides an overview of the process required for a comprehensive analysis for power system planning.

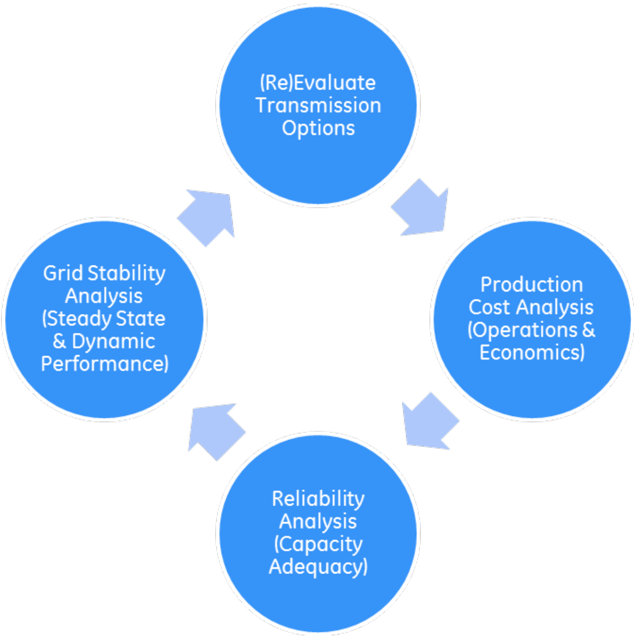

Figure 3: A comprehensive analysis for power system planning

5.1 Production Cost Studies

In order to quantify the operational changes, costs and benefits of increased transmission interconnections of a TransCanada electric transmission system, detailed chronological production cost simulations are required. This phase of the analysis would simulate the power system with detailed chronological, hourly intervals across a multi-year horizon. The modelling will simulate the role of the system operator by performing an N-1 security constrained unit commitment and economic dispatch of generators in order to serve load in a least cost manner. The modelling will provide a simulated representation of transmission flows and congestion between provinces to get a better understanding of utilization, direction and magnitude of power flows, and patterns of interchange over the course of a day and across seasons. The "chronological" aspect of production costing would be essential for accurate representation of seasonal, temporal, and locational variation of renewable energy generation.

The production cost analysis will also help to quantify the benefits of energy exchange from one region to another, the benefits of geographic dispersion of renewable resources and decreased variability, and the reserve benefits associated with a larger, more diverse balancing area. The production cost analysis can also be done in isolation, one transmission expansion at a time. This will allow a better understanding of where transmission expansion can be targeted to achieve the largest benefits. This would be a significant outcome of the study, allowing policy makers and system planners to prioritize the development of a future grid.

Lastly, this analysis would quantify the emissions reductions of environmental pollutants (including CO_2, NO_X, and SO_X) resulting in increased efficiency and a broader use of renewable resources. As shown in the Pan-Canadian Wind Integration Study (PCWIS), reduced emissions from increased renewable generation is not isolated to the province, or even country, where the asset is located. The emission reductions will span across boundaries and benefits are shared by all regions.

5.2 Reliability and Capacity Adequacy Studies

The benefits of a TransCanada electric power system are not limited to transferring energy from one region to another. Capacity adequacy and reliability is a critical component of power system planning. Increasing the size of the system will allow capacity sharing and a more diverse load profile. This could yield significant capacity adequacy benefits, measured by loss-of-load-expectation (LOLE), and reduce and delay the need for new equipment. This is especially true when transmission expansion can coordinate between regions with different seasonal load profiles. For example, a Canadian region with a summer peak load (Ontario) will have excess capacity during the winter, which can be shared with neighboring winter peaking systems (Quebec or Manitoba). The same is true for winter peaking systems in Canada, and their summer peaking counterparts in the United States.

In addition to the seasonal diversity benefits, there may also be firm capacity benefits of wind and solar across a wide geographic footprint. As the distance between wind and solar sites increases, the correlation of the resource availability decreases. A TransCanada electric power system would span across weather fronts and across time zones. This would smooth out the variability and reduce the uncertainty associated with wind and solar resources. As a result, a greater percentage of the wind and solar capacity could be counted on as a firm capacity resource, also decreasing the need for additional investment from conventional resources.

5.3 Grid Stability Studies

Finally, the North American bulk transmission system is one of the largest interconnected power systems in the world. By increasing the linkages between the Eastern and Western Interconnections, the manifold operational intricacies of the power system will be exacerbated. Detailed power flow analyses, both steady state and dynamic, would be required to better understand the frequency response implications of a future grid. As renewable integration increases and synchronous generators are displaced, potential implications become even more critical. In addition, voltages stability and weak grid concerns may also become more precarious, requiring a better understanding of the local implications of an interconnected system relying on HVDC transmission. As a result, a comprehensive analysis of the TransCanada electric power system needs to include detailed simulation base grid stability analyses. Again, the stability studies should be done in coordination with the other two studies. A TransCanada grid will dramatically change the utilization of resources across the country, requiring a linkage to production cost analyses to provide an accurate representation of the grid operations.

Fortunately it is possible today to solve simultaneously, both in steady state and dynamically, all asynchronous areas such as WECC, ERCOT, the Eastern Interconnect and Quebec, using parallel and hybrid simulation between electromagnetic transients and phasor solutions of power flow and transient stability [5]. Such analysis methods will allow the frequency response benefits to be evaluated.

5.4 Future Studies

Taken together this suite of power systems studies will provide a detailed understanding of the TransCanada electric power system. Robust engineering and economic analysis are required across all stages of power system planning in order to educate key industry stakeholders, quantify the costs and benefits, to maintain system reliability, and ensure a safe and pragmatic operation of the grid.

The PCWIS study has led the way for a North American renewable energy integration study (NARIS) for Canada, USA and Mexico. This is being undertaken at the National Renewable Energy Laboratory in Golden, Colorado. Natural Resources Canada and some of the participants in the PCWIS study and this paper are involved. A continental macro grid will be essential to realize the objectives of NARIS.

6. CONCLUSIONS

Concepts and study results reported in this document are intended as a starting point for a process that will require intensive creative effort. To develop the regulatory construct, enabling provincial legislation and financing arrangements will be challenging, the most difficult of which will be enabling legislation which can easily be bogging down by politics. Solving these matters exceed the engineering challenges. Addressing them, can remove barrier to potentially huge electricity cost savings and accelerated reductions in greenhouse gas emissions.

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