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**Integrating the Energy Markets in North-America :
Conditions Helping Large-scale Integration of Wind Power?**

By

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Abstract

The intermittency of wind resources may appear as an important handicap for integrating large-scale wind power in existing grids. However, in Canada and the United States, studies^{1,2,3,4,5,6} show that coordination between interconnected power systems can be economically beneficial for both the wind power and electric utility industries if some power system management and market rules are applied. In order to avoid power shortage, our results show that the primary condition helping large-scale integration of wind power is related to changes in market structure rules. If the system is operated in an optimal coordinated manner, on a daily basis for example, the addition of wind power can better optimize the economic operation of the overall system, thereby hopefully increasing revenues from wind power projects, and decreasing costs for the utility and its rate payers.

This paper first presents the main elements of the generation optimization model used to compute the benefits of integrating wind power in: a) a hydro-based system (using the largest power system in Canada as a test case; and b) a thermal-based system (using Vermont as a test case). Further, the authors discuss the conditions and rules needed in the generation model to alleviate operational limitations and constraints frequently associated with the intermittent nature of wind. These conditions include market rules, utility management practices, physical constraints like transmission capacities, load profiles, storage characteristics, wind resource patterns, wind power forecasting, and many other aspects.

1.- Background

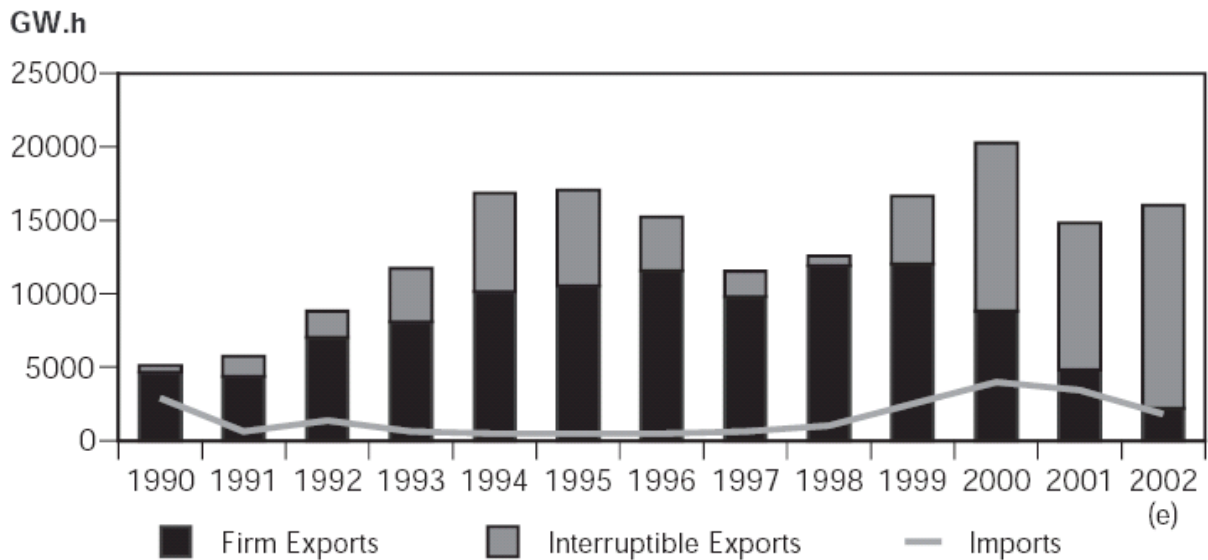
The traditional approach used by utilities to choose a generation power technology is based on a linear programming model that finds the minimum cost of generation portfolio for a given load. Submitted to base, medium and peak load constraints, this approach assumes that, at every time step, the cheapest generation technology is used. The results for this situation imply a specialization for each technology: without any surprises, conventional hydro or thermal plants including nuclear are chosen for base load, gas turbine or diesel for peak load.

Even if this approach is still the best way to determine a generation mix for a long term period for an autonomous power system, it has its limitations when one considers new issues like energy market integration. For instance, changes in electricity market structures in North America completely modified the energy exchange conditions and contracts between Canada and USA in the last decade. While in the 1980s most Canadian utilities signed firm energy contracts with neighbouring USA States, the new market context now favours interruptible exports (see Figure 1 for the Québec Case).

After a substantial increase in the early 1990s, largely resulting from the use of spare capacity in Manitoba, Ontario and Québec, Canadian electricity exports have typically been in the range of 35 to 45 TWh per year. Québec has historically registered the highest electricity exports among all provinces. Its share of total Canadian electricity exports has generally exceeded 30 percent, with an all-time peak of 42% in 1995. Since the opening of the northeastern U.S. wholesale markets, Québec's net exports grew significantly from 11.5 TWh in 1997 to a peak of 20.2 TWh in 2000. Exports tend to decline since that time partly because of lower energy surplus.

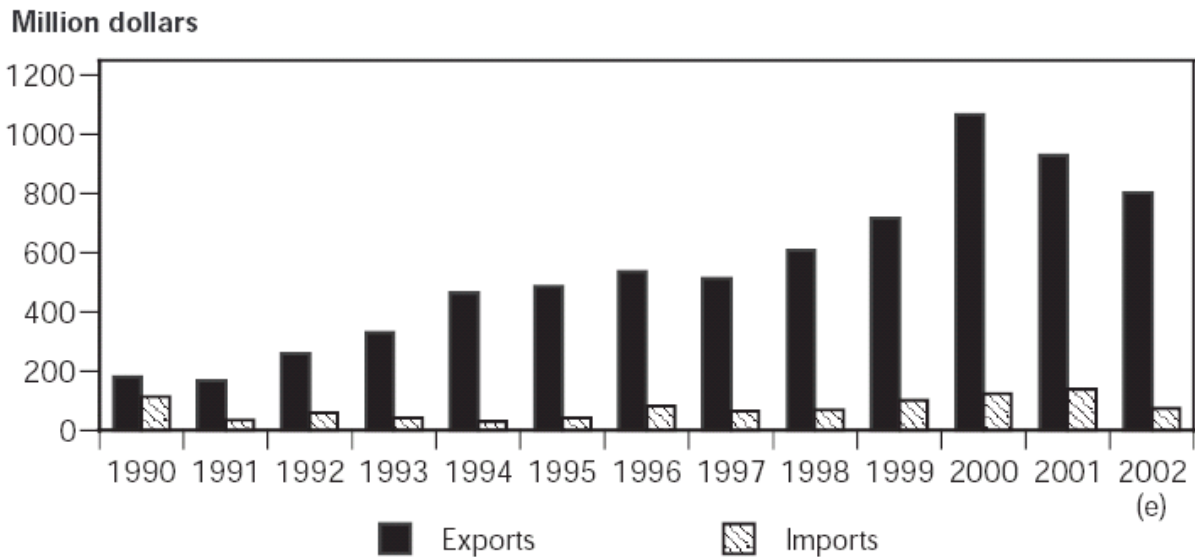
A flexible electricity generation source in Canada can benefit to the global reliability and security in USA. Statistically, on each side of the border, utilities can count on the neighbouring networks to satisfy their peak load: in the winter time for Canada and in the summer time for USA (becoming a growing issue with energy integration). If the load growth is expected low, the real issue is thus to maximize interconnection capacity factor with other networks. It should be noticed that HQ TransÉnergie had (at year end 2001) 15 interprovincial and international interconnections with neighboring systems, with a total transit capability of 7,400 MW.

Figure 1 Québec Exports and Imports(1990 - 2002)



Source: NEB

Figure 2: Québec Export Revenue and Import Costs



Source: NEB

Notes:

In year 2000, total installed power capacity in Canada was about 110,000 MW. Primary electricity generation was 62.4 percent hydro, 12.0 percent nuclear and 25.6 percent fossils fuels. These reservoirs are mainly located in the Québec/Labrador region (61% of the Canadian capacity). The hydro-based system has a competitive edge in an open market for two main reasons: a) Hydro generating units can start and generate electricity more faster than thermal units; b) Canada's hydro-based system can count on huge reservoirs that can be managed on a multi annual basis. In the new integrating system, each player tends to specialize its action. Canada's power system appears more and more as a "peaker" of the enlarged system.

1.1 The hydro/wind concept

When wind turbines represents a significant share of the total power generation system, as it is already the case in some European regions, the management practices will no longer determine the priority of utilization for a given load level on the sole basis of pure economic competitiveness of a technology. Many reasons change the management context in the electricity industry, especially for short and medium term energy planning. Changes in energy market structure influence the load security reserve management by transferring a part of the risk coverage on neighbouring systems. According to larger energy exchanges between power systems, generation portfolio is modified in order to maximize the use of existing facilities, namely reservoirs and peak load thermal plants. The intermittence of wind power supply forces utilities to use wind when available. Any other planning options decrease the competitiveness of wind.

So the integration of wind power in a large hydro-based system can be an option to improve the annual management of reservoirs for some conditions. For instance, the best context for the hydro/wind concept implies a complementary energy exchange between neighboring networks in order to reduce the risk of lack of power in peak periods. The capacity factor of wind power option is therefore optimized, while the reservoirs play the role of a regional "battery".

One question therefore arises: how large can be the share of wind power in an existing hydro-based system before significant investments in new dams and/or in generation sources as well as in new transmission capacities? Such a study was conducted for the Québec/Labrador power system, the largest power system in Canada with total generation capacity of around 40,000 MW, including a large share of hydropower reservoirs.

1.2 Integration of wind power in a thermal based system

In 2001, DOE supported a cost shared study to assess "Wind and Biomass Integration Scenarios in Vermont." Princeton Energy Resources International (PERI), working with Green Mountain Power Corporation, the State of Vermont Department of Public Service, and Hydro-Québec, conducted the study. This effort evaluated the impacts of high penetration levels of wind and biomass energy on the grid of Vermont (and adjoining areas) to determine: (1) transmission and distribution grid systems changes needed, (2) grid operation and control issues, (3) ways to minimize increases in the cost of energy to the consumer, (4) potential environmental benefits, and (5) the incremental cost of renewable energy capacity additions.

As for Québec/Labrador, the study approach was to assess the impacts and conditions associated with introduction of a large amount of wind power without investing in other generation or transmission capacities. Energy from the hypothetical wind plants was thus considered on a "must take" basis, provided the power system could handle the energy electrically and remain operationally reliable. It was assumed that all wind energy could be used somewhere in the NEPOOL or in other power system (see figure 4 for interconnections of Vermont with other power systems including Québec/Labrador). Compared the hydro/wind concept, the energy reserve in this case is only in the market, since no large reservoir management is possible in the State.

2.- Methodology

For both studies, the methodology used, as a main building block, an existing hydrothermal medium-term generation planning (MTGP) model first developed at the Hydro-Québec Research Institute (IREQ). This model was previously modified for assessing wind penetration on Hydro-Québec's power system (see references 1, 2 and 3 for these first works). The general purpose of such a model is to optimize power system operation for a period that includes timely load profile cycles analyzed for a full year duration.

2.1 Hydro-based system

In a hydro-based power system, the terms of the objective function are a monetary value function of the final hydro reservoir storages, the costs of thermal generation, and energy purchase costs and selling revenues. The optimization is

subject to water flow conservation constraints, load constraints and various operational bounds on hydraulic variables (reservoirs levels, river flows,...) and electrical variables (plant generations, power flows, ...). For the purpose of this paper, the model is assumed deterministic: water inflows, load, unit availability and wind speed are assumed to be known in advance, for various scenarios.

To model the existing Quebec/Labrador power generation system, two types of energy sources were defined: a) the hydroelectric component that represents the major share of the Quebec production system, and b) secondary sources.

The originality of the approach is to fix the final levels of reservoirs are their initial level (one year horizon). The comparison of the two energy sources is made in two steps. Firstly, we add the same quantity of energy into the system. Secondly, we look at the reduction of the total energy produced by secondary sources to satisfy an annual specific load. Without loss of generality, the secondary sources in the model are modelled by a virtual thermal plant (with a maximum capacity) connecting to all Quebec zones.

The objective function thus becomes a minimization function of additional energy costs (see Appendix 1 for mathematical details).

2.2 The thermal type power system

The MTGP model was also modified as shown in Figure 3 to optimize operation of the Vermont generation system, taking into account the interconnections with adjoining grids and actual hourly wind data from the Searsburg wind plant, located in the south east region of Vermont.

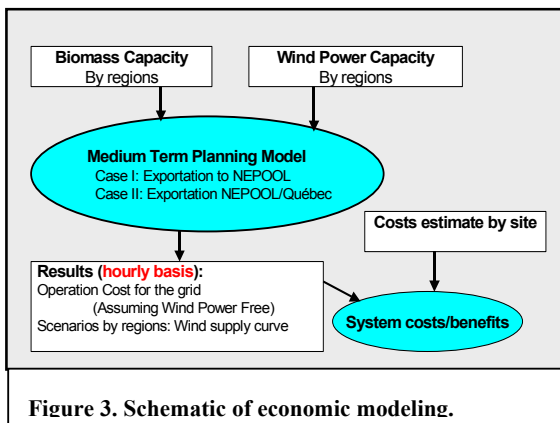


Figure 3. Schematic of economic modeling.

It was assumed, for modeling purposes, that the Vermont generation system is operated in an optimal coordinated manner rather than in a decentralized competitive manner. That assumption means two main agreements for Vermont utilities: a) together, they provide a demand forecast for the State on a daily basis and an update on a hourly basis; b) they announce in advance the determined power generation capacity for wind power and for other small plants, like hydro and biomass plants. On their side, the NEPOOL planning group insures the lack of power needed for that day. Consequently, such agreements mean that the wind power industry can provide a confident forecast for wind on a daily/hourly basis.

In summary, the goal of the analysis is to identify the least cost way to complement the wind generation. That “complementary” generation could be provided either through interconnections to neighbouring grids or by existing and/or additional backup power generation units connected to the Vermont grid system. In all instances, the transmission line capacity and electricity generation costs are accounted for in comparing scenarios.

Two cases were considered to evaluate the economic effect of adding the wind plant. In one Case the wind energy is used in the NEPOOL system at the spot price for electricity. In the second Case wind energy could be exported and used in Canada. From a modelling point of view, the MTGP Vermont model for Case 1 is easier to solve than for the Québec/Labrador model, since the water flow conservation constraints are not consider in the model.

3.0 Results

3.1 The Vermont study results

The first step was to update the assessment of available wind resource to determine if the state is resource constrained, regardless of the economics of wind power. A detailed description of the analysis is available in a report on PERI’s web site <http://www.perihq.com/whats-new.html>.

The target year for the modeling was 2010. Based on the trend over the last decade, it is assumed that, apart from wind and biomass, no other new generating capacity will be installed in Vermont over the next decade. The year 2000 load curve was forecasted to year 2010 according to demand growth projections for each of four regions in the state shown in Figure 4. The expected annual growth rate for the state is 3.3% that resulted in an estimated 1.4 GW peak load in 2010. Wholesale electricity prices were set to be the same on all links represented in the model and remains constant in real terms. Such an assumption means that Vermont demand for NEPOOL electricity would not influence the purchase/sale

price in the New England area. The hourly price variations are based on year 2000 record.

One of the important findings of this research is that there are no major system integration constraints to preclude wind power from becoming a large share of Vermont's power generation system. The study assumed that previously planned transmission upgrades would be implemented and that neighbouring markets would accept the energy surplus from wind plants providing needed power when there is a lack of wind energy. The results from the simulations showed that no congestion is expected to occur on main internal and external ties of Vermont when 810 MW of wind capacity is installed within the state. Integrating such capacity in the grid, at first may seem unrealistic, but this finding needs to be considered in the context that the Vermont power system is small compared to neighbouring power systems. As such, Vermont relies on a set of important ties to NEPOOL in the eastern and southern regions, as shown in Figure 4, to allow the load to be continuously fulfilled over time.

3.2 Results for Canada

Two conditions are simulated in the system: a) a heritage constraint of 165 TWh (in law by 2005) is simulated at a fixed price; b) for any additional demand above the heritage constraint, the price is determined by the marginal cost of new power options. For the period 2005-2011, the new generation mix is mostly set. Afterward, we suppose that all producers and distributors, including the Hydro-Québec generation division, cooperate in integrating large wind power farms in the system. As for the Vermont case, the generation system is operated in an optimal coordinated manner rather than in a decentralized competitive manner. That implies the following planning process:

- Wind power is determined and used in priority;
- The goal of the analysis is to identify the least cost way to complement the wind generation;
- This "complementary" generation could be provided either through interconnections to neighbouring grids, by existing generation capacities or by additional backup power generation units;
- The hourly price variations (purchase/sale) are based on the NEPOOL history.

By means of the latter rules, the model can compare the benefit of new power options under several market opportunities, including US wholesale market. Two cases can be tested:

Case I - the model computes the energy and peak dependence to fulfill the additional Quebec load after 2011.

Case II – When no obligation of satisfying any additional demand by 2011 is set, the model evaluate opportunities related to the promotion of wind power plant according to the spot market price.

In both case, a significant share of wind power can be managed by the Québec/Labrador system if all players work in collaborative manner. After 2011, the system is able to support at least a 10% the wind power share without power shortage. When wind is good, wind power is thus used for internal needs. Stored water in reservoirs can be used for several purposes including exports. When wind is not there, Case I supposes that Hydro-Québec can purchase power on the spot market (4 000 MW interconnections capacity to the sole US market) or can use its reserve power (about 1 500 MW by 2010). In Case II, water stored in reservoir when wind is good is used mainly for exportations.

The availability of energy is realistic simply because the entire power system, including interconnections, is in overcapacity at that time of the year (see Figure 5 and Table 1 for details). Concerning the competitiveness

For most power systems in Canada, as well as in other cold climate locations with hydro and wind power resources, wind power can improve the management of the hydro reservoir(s), creating increases in the value of wind energy, and subsequent increases in the amount of available cost-effective wind resources.

For instance, in our model, competitiveness of wind power is based on its average cost price compared to the average US wholesale market price. On that basis, it is realistic to think that the average cost price of wind power by 2010 will be lower than 8 CDN cents (converted from the 2000 US NEPOOL price).

4.0 Summary

4.1 Conditions Helping Large-Scale Integrating of Wind Power

In summary, integrated operation of large-scale wind power plants with existing power systems can deliver significant technical and economic benefits only under specific system management and market guidelines. To help large scale integration of wind power, the following conditions hold.

General conditions:

- Energy from the wind plants is considered on a “must take” basis,
- Our model assumes a complementary energy exchange between neighboring networks in order to reduce the risk of power shortage in peak periods; it means that the energy reserve is available in the system at any time that appears realistic for our two case studies;
- The system is operated in an optimal coordinated manner rather than in a decentralized competitive manner at all levels, local and regional; according to larger energy exchanges between power systems all players are involved: producers, distributors, strategic managers and any other groups work to maximize the use of existing facilities, namely reservoirs, peak load thermal plants and interconnection capacities; that means a centralized management of the generation portfolio at the regional level: ex NEPOOL ISO.

System conditions:

- Wind power can represent a large share, provided the power system can handle the energy electrically and remain operationally stable. It is assumed that all wind energy can be used somewhere in the main system or in other interconnected power system;
- Localization of wind farms are optimized according to all parameters: wind quality, transmission line capacities, load proximity and so on. In other words, any economic analysis for wind is subjected to a system analysis. A traditional planning option based on a comparison of marginal cost for a load class decrease the value of wind power.
- Our works show that the problem is system specific; no generalization is possible except the fact wide system analysis that includes interconnections and market rules is needed to assess the impact of wind power.

Market conditions

- Since wind power is determined and used in priority, the goal of the analysis is to identify the least cost way to complement the wind generation.

Spot market prices are not influenced by the fluctuating wind power. Need a political support for the transition to competitive market and energy free trade across borders.

4.2 Conclusion

Electricity market is being driven by important changes in market structure and planning as well as in technology development like wind power and new efficient fuel turbines. The good news are that changes in market structure appear as a favourable condition to integrate large scale wind power farm in an existing grid.

Our modelling approach is enough flexible to answer a number of questions about the benefit of the hydro/wind synergy or integrating large scale wind power in Vermont. A myth falls: wind intermittence does not appear as a great problem if a system analysis is performed and if a collaborative approach of all players is in force.

Clearly, these results are very encouraging for the wind power industry. However, some warnings hold. The economics have to be respected. The wind industry has to propose competitive technologies in order to beat other alternative options. Our studies do not consider the costs of other options. In order to have the real benefit of integrating large scale wind power, a detailed economic comparison of all the alternatives should be achieved.

Finally, the confidence on the results, obtained by the deterministic modelling approach, will be validated by a stochastic approach and other. More investigation and statistical analysis of different parameters are also needed to see if the hypothesis will lead to lower expectations.

Appendix 1: Medium-term generation planning model

Both Vermont and Hydro-Québec's power systems are optimized in order to find the best energy management solution. In practice, the Hydro-Québec case is more complex to model, since hydraulic constraints have to be considered.

To describe the hydro-thermal medium-term generation planning model underlying our approach, we first present the modelling hypotheses and introduce some notation; next we describe the objective function, F . The constraints of the model are not detailed in this section, but can be consulted in references 1 and 4. We first recall that the model is deterministic: all input data are assumed known in advance with certainty, including natural water inflows and wind speeds.

Notation

- T: number of time steps (weeks for Case II, hour for Case I) of the planning horizon
J: number of load classes within each time step (only one class used in this study)
NSM: number of energy sale ties
NPM: number of energy purchase ties
NTP: number of thermal plants
NZ: number of regions

Main constants

- pp_{ij}: purchase price of energy on purchase tie i during class j of time step t (\$ per MWh)
sp_{ij}: sale price of energy on sale tie i during class j of time step t (\$ per MWh)

Main variables

- TH_{ij}: power of thermal plant i during class j of time step t (MW)
PP_{ij}: power purchased on purchase tie i during class j of time step t (MW)
PS_{ij}: power sold on sale tie i during class j of time step t (MW)
X_{ij}: power flow on tie i during class j of time step t (MW)

The objective function

For our particular problem, and as opposed to the energy planning model used at Hydro-Québec (Lafrance *et al.*, 2001), the level of each reservoir is fixed at the end of the period. Thus, the objective function of the model is as follows:

$$\text{Minimize } \sum_{t=1}^T \sum_{j=1}^J \alpha_{tj} \left(- \sum_{i=1}^{NSM} sp_{ij} PS_{ij} + \sum_{i=1}^{NPM} pp_{ij} PP_{ij} - \sum_{i=1}^{NTP} tc_{ij} TH_{ij} \right) \text{ where}$$

α_{tj} is the conversion constant from MW to MWh for load class j of time step t .

Only one load class is used in the Vermont study (hourly basis). For the Québec/Labrador study, we tested two cases: one load class and 14 load classes (weekly basis).

Hydraulic constraints

The main hydraulic constraints are the classical water flow conservation equations. For each reservoir r and time step t , such a constraint states that the volume V_{rt} is equal to the volume $V_{r,t-1}$ at the beginning of time step t , plus the sum of flows from river sections into reservoir r minus the sum of flows of river sections out of reservoir r , plus the natural inflow into reservoir r , during time step t . The flow of a river section s for each time step t is of course defined as the sum of the flows of plants and spillways into that river section.

Demand constraints

For each region z and load class j of each time step t , a load constraint states that the sum of the region's generations of hydro and thermal plants plus the power purchases minus the power sales in the region, plus the net power flowing into

the region through the transmission network must equal the demand.

Elementary bounds

There are of course elementary lower and upper bounds on all electricity variables and on all the hydraulic variables

References:

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[6] J.Cohen, G. Lafrance, and S. Krau, *Analysis of Wind Hydro Integration Value in Vermont*, WINDPOWER 2003, Austin, Texas, May 21, 2003

Table 1 Québec Load and exportforecasts

Sales (Terawattshours)	2002	2011
Québec Load	158	185
Net exports	15	7
Net Exports with the Addition of about 3000 MW of Wind Power	-	15

Québec/Labrador System

Generating Power Capacity: 40 000 MW
(36% of Canadian total system)

Transfer Capability = 7 500 MW

Interconnection to the NorthEastern States:
4 425 MW

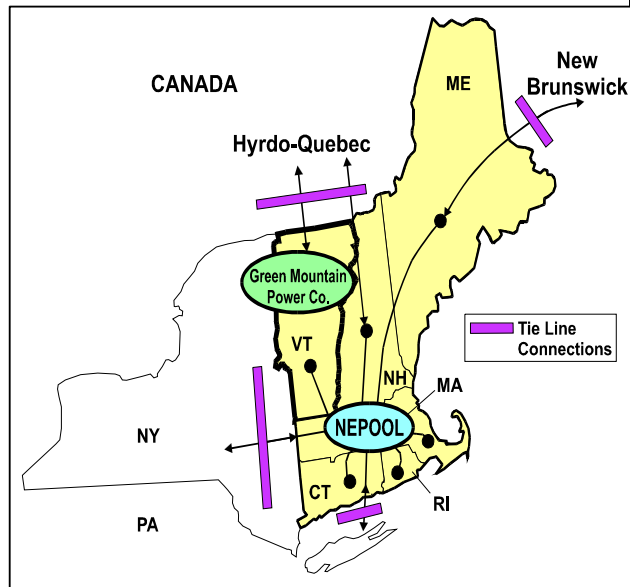


Figure 1. . Interconnection of Vermont in the New England power pool (NEPOOL)

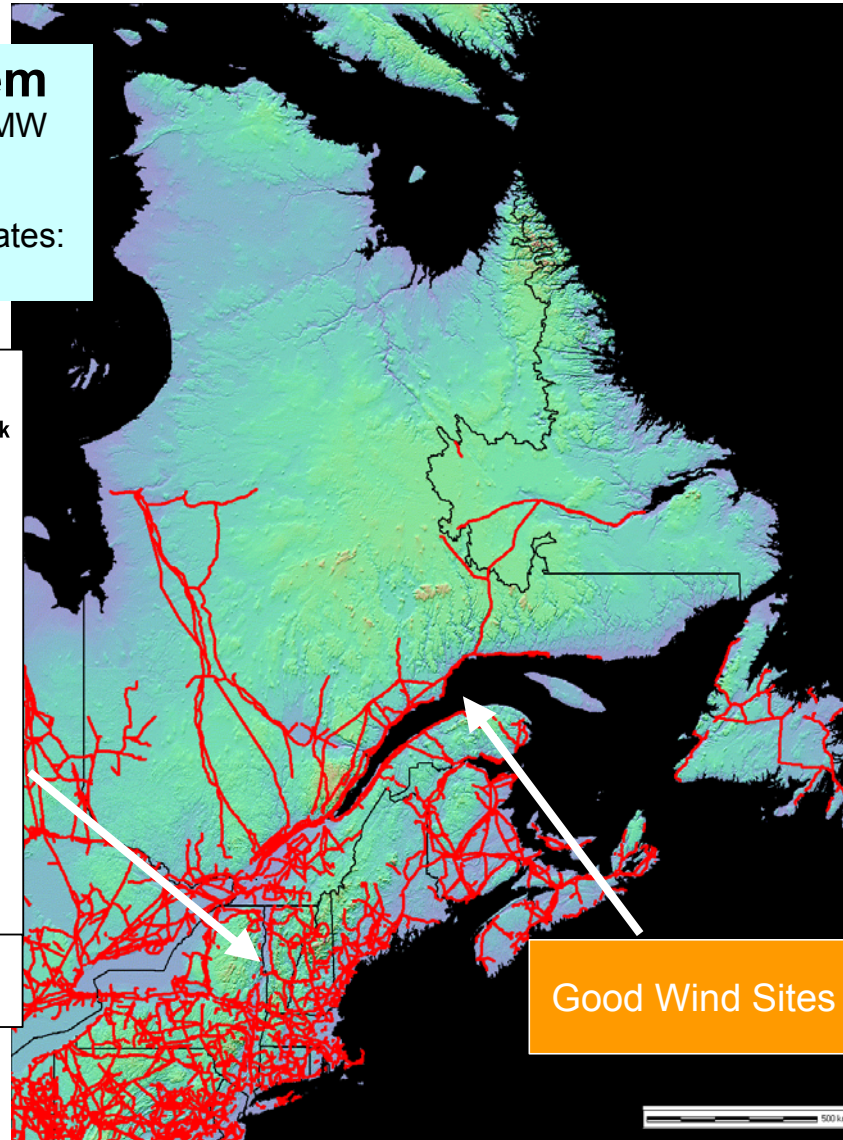


Figure 5 (has to be translated)

