A Trans-Canada HVDC Link for Better Integration of Renewable Energy

CCTC 2013 Paper Number 1569694145

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Abstract

Renewable energy (RE) resources do not match well with power demand requirements. Their variable "must take" generation leads to cycling of thermal production units with resulting increases in operation and maintenance costs of these units. Provincial segmentation of energy markets further contributes to the inefficient allocation of these generation resources. Hydro reservoirs are ideal to act as energy buffers for excess RE. A Trans-Canada HVDC (high voltage direct current) link would allow connecting RE resources with Hydro reservoirs across Canada. In the long run, implementation of such a HVDC link should result in a more efficient, environmentally friendly power system with lower electricity rates.

Keywords: CCTC2013, climate change, global warming, renewable energy, HVDC, Trans-Canada, hydro reservoirs, energy buffers

Résumé

Les ressources en énergie renouvelable (ER) ne correspondent pas bien avec les besoins en consommation d'énergie. Leur production variable doit être acceptée par le réseau et mène au cyclage des unités de production thermiques avec en conséquence des augmentations des couts de production et d'entretien. La partition par provinces des marchés d'énergie électrique contribue d'avantage a une allocation inefficace de ces ressources. Les réservoirs hydrauliques sont idéalement indiqués pour agir comme tampons d'énergie pour le surplus en ER. Un lien transcanadien en CCHT (courant continu a haute tension) permettrait la connexion des ressources en ER avec les réservoirs hydrauliques à travers le Canada. A longue échéance la réalisation de ce lien CCHT devrait aboutir en un réseau d'exploitation plus efficace, meilleur pour l'environnement et avec des taux d'électricité moindres.
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Mots clés : CCTC2013, changement climatique, réchauffement global, énergie renouvelable, CCHT, transcanadien, réservoirs hydrauliques, tampons d'énergie

1. Introduction

In a discussion on experts and global warming Gary Gutting, professor of philosophy at Notre Dame University, wrote [1] *"Once we accept the expert authority of climate science, we have no basis for supporting the minority position".* In his second inaugural address [2] President Obama aligned the U.S. to the majority position of combating anthropogenic global warming. The world is presently moving to non-carbon energy resources in its effort to reduce green house gas (GHG) emissions. Renewable energy will play a significant role in tomorrow's energy supply; public support is high and momentum has been established [3].

In North America electricity represents 40% of total energy use. Any increase in efficiency in this sector will have an immediate impact on GHG reduction. In Canada there are presently major initiatives to install wind farms and thus reduce its carbon footprint; however, constraints exist on how much energy the regional systems can absorb.

This paper will focus on describing these constraints, how they can be minimized and how total system efficiency and reliability can be increased by establishing high voltage, high power transmission links between provincially focused and regional systems, ultimately resulting in a coast to coast HVDC energy super highway.

2. Generation resources in Canada

Canada is blessed with large amounts of hydro power. With the addition of existing nuclear generation Canada ranks among the top three countries with regard to the Energy Sustainability Index as quoted in the World Energy Council's latest report [4]. Figure 1 shows the electricity supply mix for 2011 [5]. Wind is still a small fraction of total generation but is expanding rapidly. This is following a world wide trend. In the International Energy Agency's 2012 report it is stated that a steady increase in hydropower and the rapid expansion of wind and solar power has cemented the position of renewables as an indispensable part of the global energy mix; by 2035, renewables will account for almost one-third of total electricity output [6].

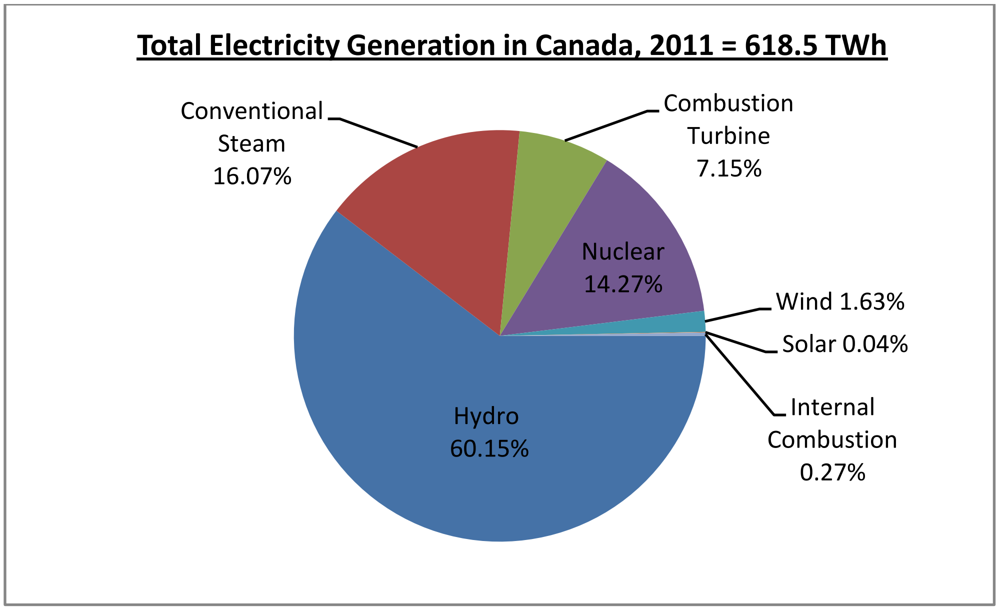

Figure 1. Electricity supply mix

Quebec is following a strategy of further developing hydroelectric power to meet local demand, stimulate industrial production and export electric energy to neighbouring Provinces and States. With the latest calls for tender, Quebec's installed wind capacity will reach 4,000 MW by 2015 which represents approximately 10% of total peak demand [7]. At these levels wind energy can no longer be ignored with regard to capacity fluctuations and in its effects on load despatching.

Other provinces are following a similar path to increased renewable energy production. In Alberta wind generating capacity is presently at 7.5% of total generating capacity. In Ontario it is 6.5%. Excepting hydro and nuclear, two thirds of the remaining (high GHG emitting technology) is over 30 years old providing opportunity for replacement with renewable energy [8].

3. Constraints on renewable generation

In a stable electrical system, demand for electrical power (the load) will always to be supplied by generating resources of various types. These generating assets can be large coal fired or nuclear units, gas turbines or combined cycle gas turbines, large hydro-electric units and increasingly by renewable energy generation such as small hydro, wind, solar, geothermal, etc..

The demand for electrical power depends on the time of year, the outside temperature, the day of the week and the time of day. For example the demand for power in Ontario on 4 February 2013 was as shown in Figure 2.

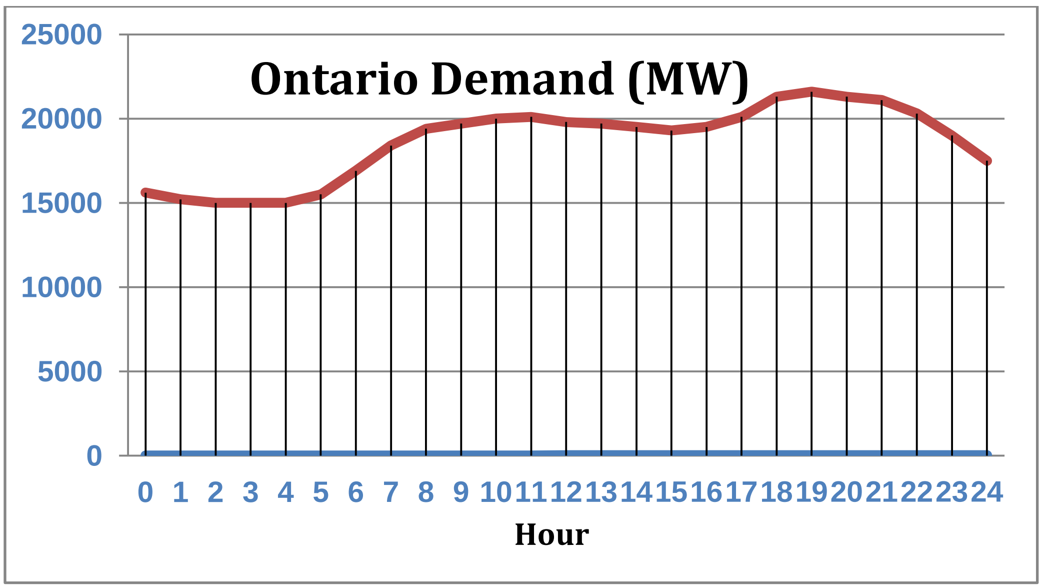

Figure 2. Ontario demand (4 February 2013)

The figure shows that on that day peak load was about 22,000 MW and that the demand never dropped below 15,000 MW (the base load). The balancing of power generation with load (despatching) is a complex task. Ideally, the system operator seeks to meet the system load at the lowest possible cost with consideration of operational and system constraints.

Traditionally, large coal fired and nuclear power plants, as well as large hydro-electric generating plants, have provided the most economic way to supply base load. The size of current thermal generating units (1000 MW) dictates that they should be used in the most efficient manner. This is especially true for coal fired plants which, with thermal generating efficiencies around 45% under optimum coal burning conditions, emit large amounts of CO^2. This volume of emissions is better understood when one realizes that a 1000 MW plant requires

9000 tonnes of coal per day (equivalent to the supply of one unit train load consisting of 100 90-ton cars every day).

Cycling operations, that include on/off startup/shutdown operations, on-load cycling, and high frequency MW changes for automatic generation control (AGC), can be very damaging to power generation equipment. This is especially true when the plants have not been designed for cycling operations. A comprehensive analysis conducted on more than 150 coal-fired units has shown that the financial costs associated with cycling operation are very high [9].

The inclusion of a significant amount of renewable energy into power systems has resulted in additional constraints on economic load dispatch (ELD) to accommodate the intermittent nature of the wind, solar or ocean output. Unfortunately, maximum renewable energy production rarely occurs at times of peak power demand. For example, in Ontario wind velocities peak in the early morning when demand for electric energy is low.

Ontario and Alberta have very limited hydroelectric storage. Consequently, there is no easy means to accommodate intermittent sources such as wind or solar. Unless these sources can be taken off line (which contractually they can't) existing thermal generating units need to adjust their output. Wind energy is must-take energy; hence, when wind dies thermal units have to be put in service When wind is high thermal units have to be ramped down; they cannot be shut off because the thermal cycling caused by too many starts and stops will damage the units. Consequently, often steam will be released (energy will be dumped) reducing efficiency of the installation locally and the system more broadly. As noted above, the resulting ramping or cycling of these units is not a desirable feature since metal fatigue in the boiler, feed tubes and condensers together with the fact that the units operate at less than peak efficiency contribute to increased operating and maintenance costs.

The dumping of wind energy directly (or indirectly by steam venting in thermal units and steam bypassing in nuclear base load plants) can be avoided if this energy can somehow be stored.

4. Energy storage / Energy buffers

Electrical energy can be stored in a variety of ways. The best know storage device is of course the battery. In the beginning of February 2013 the world's largest battery system was put on line in Texas capable of delivering 36 MW of windpower to the grid over a period of 15 minutes [10]. This battery system is the first in a wave of new grid-connected storage and electrical energy buffer systems funded in 2009 by power companies and the US Department of Energy (DOE) that are expected to come online this year.

A more familiar way of storing energy is the pumped storage system where pumps will fill an elevated reservoir during times of low demand and inexpensive energy rates. Subsequently, the penstocks will be opened and the water will flow back down through the turbines during times of peak demand. While this system normally requires terrain topography which is amenable to water storage it is now also envisaged in the North Sea where construction of an atoll is being proposed to store wind energy and deal with peak demand [11]. Water would be pumped in the atoll during low demand and produce electrical power during peak demand. Figure 3 shows what this would look like.

Figure 3. An atoll to provide energy storage

These forms of energy storage are expensive. In Canada, however, we are blessed with an abundance of hydro-electric facilities (and remaining potential) spanning the country from BC to Labrador. Hydroelectric facilities consisting of dams with large reservoirs are ideal to store excess energy except at certain times of the year where heavy rain and/or melting of snow and ice will fill the reservoirs and water spilling may be required. At present, installed hydro-electric generating capacity in Canada is about 76,000 MW. The water reservoirs associated with this generating capacity provide ample room to store surplus wind energy subject of course to the provision of suitable transmission interconnections and modified despatching procedures.

It should be noted that wind energy storage is already used in Northern Europe where large wind farms in Holland, Denmark and Northern Germany are connected through submarine HVDC ties to hydro-electric facilities in Scandinavia.

5. The case for energy super highways

Reliably integrating high levels of variable resources — wind, solar, ocean, and some forms of hydro — into the North American bulk power system will require significant changes to traditional methods used for system planning and operation [12]. According to the North American Reliability Corporation (NERC) 2008 Long-Term Reliability Assessment, over 145,000 MW of new variable resources are projected to be added to the North American bulk power system in the next decade. The largest portion of these 145,000 MW renewable energy sources will be supplied by wind farms. Figure 4 shows where the best wind generating potential sites would be located (blue) and where the largest demand for electrical energy occurs (red).

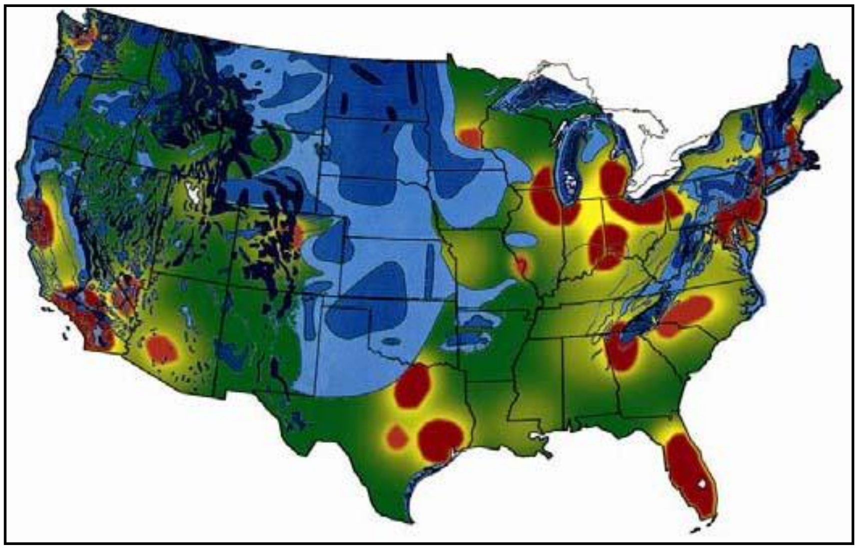

Figure 4. Wind availability and demand centres in the US

The case for a national grid in Canada was made in the Canadian Society for Senior Engineers (CSSE) "Energy Compass" advocacy report [13] which noted that Canada needs a nation-wide electrical grid, mainly for security and economic reasons, particularly with the growing probability of cyber attacks on electrical plants and control systems.

A 2010 report by the Canada Power Grid Task Force of the Canadian Academy of Engineering (CAE) [14] recommended that:

- **As an Immediate Infrastructure Project**, fund on a cost-shared basis with provinces and possibly the private sector, new electrical grid interconnections between two or more provinces based on cost benefit analyses of the longer-term national strategic value of achieving some of the following goals:
  - reduced GHG emissions through improved access by renewables such as large hydro and wind,
  - enhanced energy storage capability,
  - reduced energy costs by the receiving province(s),
  - new markets for stranded or new power generation, and
  - the strategic security advantages of developing a high capacity trans-Canada transmission backbone.

- **As a Long Term Plan**, establish and fund a Cross-Sectoral Management Entity to prepare a technology and business framework for the electrical industry investments needed over the next 25 years to capture wealth generation opportunities and to address GHG issues. The entity should examine initially two scenarios:
  - the interconnection and strengthening of the Canadian electricity grid, enabling the passage of large blocks of power both east-west and north-south to the U.S.,
  - the above 'basic' scenario, with expanded interconnections to an anticipated U.S. east-west electrical grid to provide an intercontinental electrical network.

A 2012 subsequent report prepared by the CAE Energy Pathways Task Force [15] further recommended that "Canada should connect existing provincial electricity grids through a new high-capacity transmission system. This would enable significant reductions in Canada's carbon footprint by incorporating distant hydroelectric and tidal low-GHG electric power stations to replace aging coal-fired and other thermal power generating stations, when retired, and meet new demand. The business case for variable renewable energy ventures (wind, bioenergy, solar, tidal, wave) would also be improved". The report proposes that 735 kV with compensation would be able to provide these interconnections on a continental scale.

Of all the renewable energy options wind generated electrical power is the more prominent option and is being developed aggressively in Canada and the United States. Figure 4 shows clearly how interconnections between East and West would allow wind farms to connect to major load centres and to major hydro-electric facilities.

Electrical power falls under the jurisdiction of provincial governments. Hence, most system planning takes place at the provincial level. There is less than optimum overall regional, national or international system planning. Canada has more interconnections with the US than it has among all the provinces. The interprovincial connections tend to have small transfer capabilities whereas many of the interconnections to the US can transfer quantities equivalent to the output from major hydro or nuclear plants [14].

From an operations point of view, the provinces are part of three U.S. power pools. From Figure 5 we see that Canadian provinces are part of:

- WECC (Western Electricity Coordinating Council)
- MRO (Midwest Reliability Organization)
- NPCC (Northeast Power Coordinating Council)

The pools ensure that stability is maintained within the pool during system disturbances. Quebec is a special case as it is coupled only asynchronously to the NPCC pool through HVDC transmission lines or back-to-back HVDC converter stations.

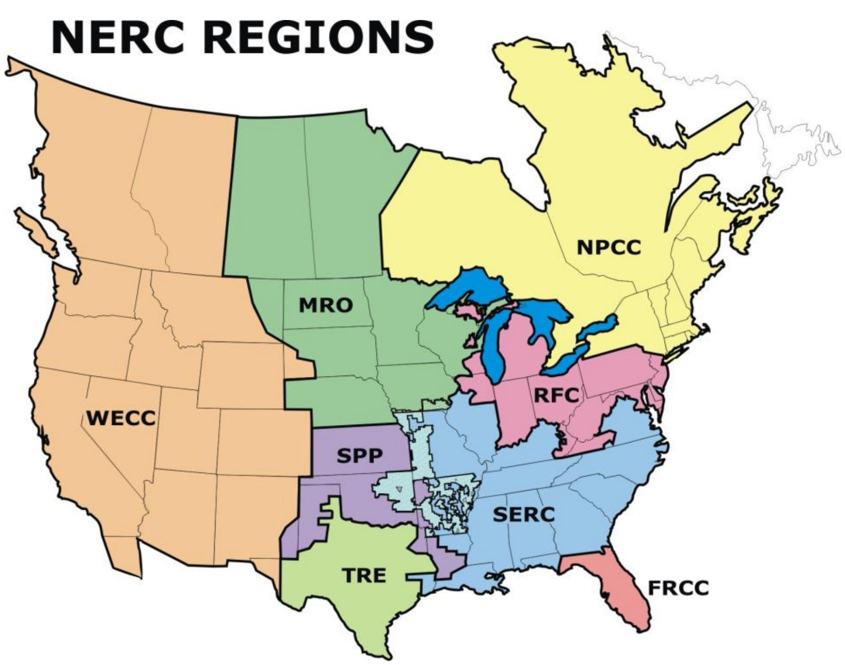

Figure 5. North American Power Pools

System planning in the US takes place at the pool level which covers a number of States. For example WECC members, recognizing the need for a regional approach to transmission expansion planning, organized the Transmission Expansion Planning Policy Committee (TEPPC) to provide transmission expansion planning coordination and leadership across the Western Interconnection. TEPPC is funded, in part, by a grant from the U.S. Department of Energy. Their latest planning report [16] includes as one of the planning themes the aggressive development of wind generated facilities in Wyoming and Montana. As a result of the abundance of wind energy in these States, wind as a must-take energy resource would be able to supply, on a windy day, total local peak load forcing existing coal plants to dump energy.

Therefore it becomes essential for the development of these wind resources to export surplus energy to the distant load centres of Southern Nevada and California. A favored option that came out of the plan was an HVDC line connecting Wyoming to Southern Nevada. This option is called the TransWest Express HVDC interconnection.

It is important to realize that 25% of the electric energy produced in the WECC pool comes from conventional hydro and that good ties already exist from British Columbia to California which will enable a smoother integration of the Wyoming wind farms into the WECC pool.

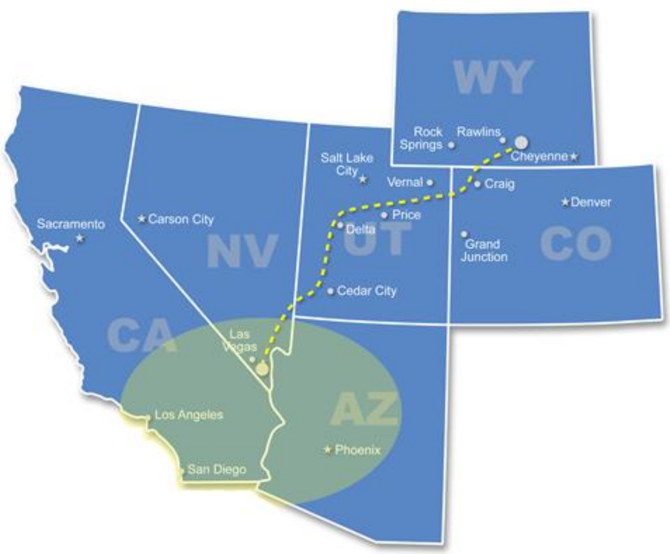

Figure 6. TransWest Express HVDC Interconnection

The 3,000 MW capacity, +/-600 kV, 1200 km long TransWest Express HVDC interconnection is expected to begin construction in 2014 at an estimated cost of 3B$.
(Source: www.transwestexpress.net).

This energy super highway can be considered as one of the first elements in a continent wide super grid which would enable electrical energy to be whisked, at close to light speed, to the areas where it will be required either for use or storage. Existing and potentially new hydro reservoirs would provide the storage systems which would make the North American power system more efficient and reliable. The availability of large hydro reservoirs in Canada makes a Trans-Canada HVDC interconnection a prime candidate for further study and implementation.

A piecemeal implementation could see for example:

- In the West, an HVDC link between the Peace River area in BC and the future Northern convertor station of Alberta's East 500 kV HVDC line. The Peace River area has three major hydro-electric facilities (including the future Site C) and very large wind generation potential. The Northern convertor station location is situated North-East of Edmonton and close to the oil sands. The interconnection would thus tie hydro reservoirs and wind farms in the Peace River area to the large demand zone of Edmonton and Northern Alberta's oil sands. Through the Eastern HVDC line it could also connect wind farms in Southern Alberta and Montana to the hydro reservoirs. And it would provide an alternative path to Peace River's radial generation system in BC.

- In the East, an HVDC link between Quebec's James Bay hydro-electric facilities and Ontario's 500 kV grid should be very beneficial to both provinces. There is already a back-to-back HVDC station with a 1250 MW capacity which ties Quebec's 315 kV system to Ontario's 240 kV system but a more powerful connection is needed to help alleviate Ontario's cycling problems and help replacing its aging fossil-fuel generating stations.

With different provincial players in a national demand-supply network, dispatching energy from the reservoirs into interprovincial and international grids will become a challenging issue for the appropriate government agencies interested in a new energy paradigm. Perhaps a task force consisting of NERC and three U.S. connected power pools, the National Energy Board (NEB) and the major Canadian provincial system operators could be considered for further study of this "operational research" problem which would deal with the optimization of dispatching rules under a number of system constraints. In the West, the Pacific NorthWest Economic Region (PNWER) [17] organization Energy Committee comprising ten states, provinces and territories could facilitate such an initiative with the WECC.

6. Why HVDC?

There are many advantages HVDC lines have over equivalent alternative current (ac) lines once the line length exceeds 400 to 500 km. They are:

1. Cost. Because the HVDC line uses only two poles as compared to the three phases of an ac line, the HVDC line will be about 70% of the ac cost. For example the Itaipu hydro-electric facility in Brazil uses two 600 kV HVDC bipoles to transmit 6,300 MW of power. An ac option would have been to use three series compensated 735 kV transmission lines. Two additional substations would have been required in the line to maintain the voltage profile [18]. Costs savings will increase with line length.

2. Transmission capacity. An HVDC line, depending on voltage, can transmit 4000 to 6000 MW. No ac line can transmit that amount of power. This results in fewer lines required to transmit major blocs of power (less right-of-way).

3. A bipole HVDC transmission line consists of basically two circuits, positive and negative, and can still operate with a fault on one pole or in the converter equipment connected to that pole.

4. Greater control. Thyristor control allows for much easier control of the power flow, in either direction, on the HVDC line. This allows for greater operational flexibility. An

HVDC link between power pools provides an asynchronous link preventing a system imbalance in one pool from affecting the neighbouring pool. It can actually play a supporting role in maintaining stability of the pool under duress.

5. Environmental. A reduced right-of-way width and the absence of induced electro-magnetic fields are major environmental advantages of HVDC transmission.

6. Energy conservation. Line losses in HVDC over extended distances are lower than ac over the same distances.

7. Conclusion

The development and integration of renewable energy in North America rests on the development of transmission interconnections between the wind farms and the major load centres. In order to replace aging coal fired generating plants by intermittent renewable energy there is a need for energy storage to act as buffers.

Hydro-electric facilities with large reservoirs are ideally suited to provide energy storage. Canada, with 60% of its generation coming from hydro-electric facilities, can provide this energy storage. The best locations for wind farms are located in Canada and the North of the US. Interconnecting these wind farms with Canada's hydro-electric facilities by means of East-West HVDC energy highways would solve to a great extent the cycling problem thermal units have to cope with resulting in more efficient power system operation.

The Canada wide interconnection of wind farms will allow part of the intermittent wind energy to be considered as firm energy which can be used in replacing aging coal-fired power plants to the benefit of the environment.

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9. Acknowledgements

The author gratefully acknowledges the many discussions with CSSE members.

10. Biography

Guy Van Uytven is a power systems consultant with extensive experience in transmission line planning and design. He participated in the design of the 735 kV Churchill Falls (Labrador and Newfoundland), 600 kV HVDC Itaipu (Brazil), 500 kV HVDC (Eastern Alberta) and is presently involved with the 500 kV ILM (BC) transmission line. He was also project manager for a South China system planning study developing generation and transmission plans over a 25 year horizon.