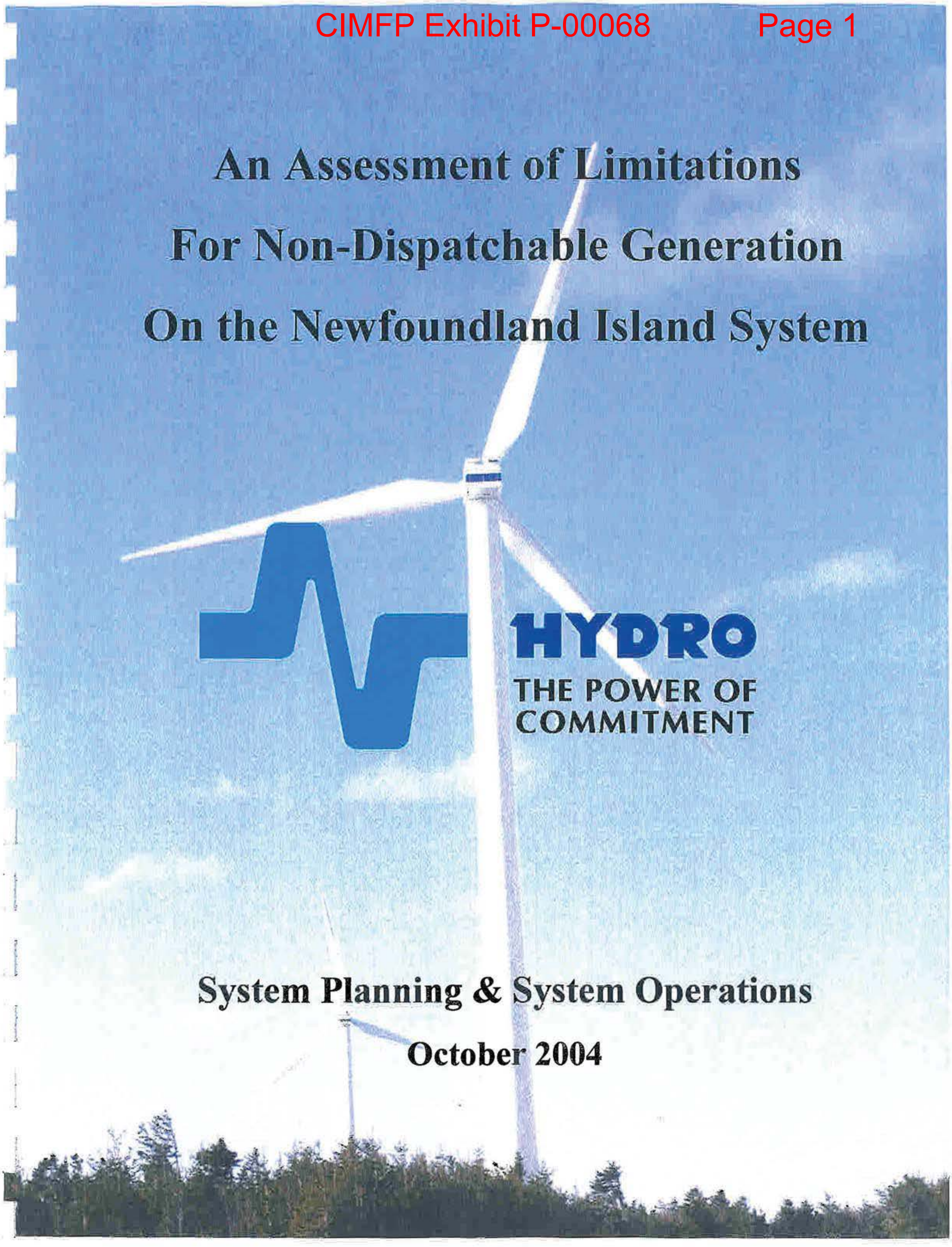
An Assessment of Limitations For Non-Dispatchable Generation On the Newfoundland Island System



HYDRO
THE POWER OF COMMITMENT

System Planning & System Operations

October 2004

Executive Summary

With no requirement for additional capacity until the 2011 timeframe, Hydro had not contemplated identifying the upper limits of wind penetration, until now. The intention was to gain direct operating experience through a wind demonstration project as outlined in the 2001 Request for Proposals. However, in the absence of the demonstration project at this time, and with the current level of interest and activity from various wind proponents interested in large-scale wind farms, Hydro has undertaken this analysis to define the scope of opportunity for wind development that currently exists on the Island of Newfoundland.

Wind generation technology offers the promise of displacing energy from fossil fired generating stations with an environmentally friendly, emissions free alternative. However, not withstanding the cost to develop wind generation facilities, the degree to which wind can displace more conventional forms of generation (such as fossil-fueled plants and large hydroelectric facilities) is limited by the inability of the resource to operate on demand (wind is non-dispatchable) and by the intermittent nature of the resource. The related concerns from a utility operation perspective come on two fronts; first in the availability of the generation to meet higher loads; and second on occasions of light load when non-dispatchable capacity can no longer be absorbed into the system without adverse technical and economic impacts.

In the first instance, the ability of wind generators to operate is contingent on its availability (i.e. whether or not the wind is blowing) and therefore cannot be turned on at will. It therefore cannot displace the need for and availability of generating sources that can be dispatched to meet the constantly changing customer demands. In the Newfoundland context, while wind offers the opportunity to displace a portion of the oil-fired energy produced at the Holyrood Thermal Generating Station on the Island of Newfoundland, no amount of wind capacity could displace the entire facility without significant investments in other (most likely fossil-fueled) dispatchable sources.

The focus of analyses presented in this report however, is to identify and quantify the factors that exist to influence the ultimate penetration of wind energy as it relates to the ability of the Island System to absorb the capacity particularly within periods of lighter load. Three specific key constraints that affect the operation of the Island System are water management, frequency considerations and transmission limitations. Unlike most other North American jurisdictions, these constraints are further magnified for the Island system due to the lack of an interconnection to other neighboring power systems. Accordingly, the Island System must operate as a completely self-contained system, responding to internal changes without support from outside entities.

In light of these operational constraints that are inherent to the Island System, the addition of further quantities of non-dispatchable generation that can come on-line at any output level at any time may cause the following problems:

- Less load available for hydroelectric generation operation to limit spillage of water. During periods of high inflow to Hydro's reservoirs this may result in spillage of water because the water cannot be stored and produced later;

- Lower load levels available to generation required for transmission grid security. During light load periods the non-dispatchable generation may be supplying near the total system load. Depending on the location of this non-dispatchable generation in relation to the load on the system, it may cause the transmission network to be lightly loaded resulting in high voltages. The Bay d'Espoir units used to control the voltage cannot perform that function without sufficient loading. As well, under such a minimum loading condition an upset to the system such as a loss of load could trigger the system to shutdown (i.e. a system-wide blackout); and

- Regional transmission loading concerns resulting in overvoltage conditions. Wind generation provides limited voltage control. If it displaces generation with voltage control capability, certain regions, particularly west of Bay d'Espoir, may experience high voltages that are difficult to control without added capital expense or a reduction in system security.

With respect to Hydro's ability to manage the hydroelectric resource on the Island, additional amounts of non-dispatchable wind generation up to 80 MW may be incorporated into the system with little risk of additional spill. Beyond this level, where the impact of a 20 MW increase in wind capacity from 80 to 100 MW results in an approximate doubling of the expected level of spill from 9 to 19 GWh on an average annual basis, spill becomes even more significant, and rapidly increases with each increment in wind turbine installation. To illustrate the economic value of this lost hydraulic energy capability, 19 GWh of energy at an assumed cost of 7 cents/kWh would be valued at approximately $1.3 million on an average annual basis.

With respect to just the system security limitations related to the ability of Hydro to maintain continuity of service, amounts of non-dispatchable wind generation up to 130 MW may be integrated into the system as a whole without significant technical performance repercussions. However, regional constraints further limit the distribution of this new non-dispatchable generation on the system west of Bay d'Espoir to no more than 70 MW, and to no more than 60 MW on the system east of Bay d'Espoir, or conversely, 90 MW in the Eastern region would result in no more than 40 MW in the West.

Based on the level of analyses performed, and taking into consideration each of the limiting factors it would appear at this time it would be prudent to set an upper limit of 80 MW of wind generation that could be incorporated into the Island System with few adverse effects. However, given the preliminary nature of this investigation, it would be prudent to further limit the initial quantities of wind generation into the system. Consideration should be given to a step-wise pattern of increased penetration levels over a number of years to gain direct operating experience with the technology and its integration into the Island system. This would allow Hydro to further define the opportunities and constraints associated with the resource without subjecting customers to undue expense or power quality issues. As well it would allow the industry to arrive at possible solutions which, along with the experience gained by Hydro, may permit penetration levels beyond those currently identified

Amounts of non-dispatchable generation, including wind, beyond these levels would require further and more detailed analysis of potential impacts to identify the full cost to Hydro and its rate-payers. In addition it must be clear that the levels identified herein apply to widely distributed resources connected to Hydro's bulk transmission system. To maintain the general nature of these findings, no attempt has been made to incorporate site-specific limitations. Every project that is contemplated, wind or otherwise, must be evaluated in the context of the general concerns described above, as well as issues specific to the site.

Table of Contents

1. Introduction

Wind generation technology offers the promise of displacing energy from fossil fired generating stations with an environmentally friendly, emissions free alternative. However, not withstanding the cost to develop wind generation facilities, the degree to which wind can displace more conventional forms of generation (such as fossil-fueled plants and large hydroelectric facilities) is limited by the inability of the resource to operate on demand (wind is non-dispatchable) and by the intermittent nature of the resource. The related concerns from a utility operation perspective come on two fronts; first in the availability of the generation to meet higher loads; and second on occasions of light load when non-dispatchable capacity can no longer be absorbed into the system without adverse technical and economic impacts.

Electrical systems require equilibrium between the load demanded and the power produced through its generators. Since there is currently no cost effective, large scale method of storing electrical energy, the power system is designed to provide power at the instant the load demands it, and at the prescribed frequency and voltage limits. Variations outside of these limits can either cause protective systems to shut down large parts of the network or cause extensive damage to delivery equipment and to customers' facilities. It is in this context that the integration of wind (or any other form of) generation must be viewed by the utility charged with the secure and economic operation of the power system.

The ability of wind generators to operate is contingent on its availability (i.e. whether or not the wind is blowing) and therefore cannot be turned on at will. It therefore cannot displace the need for and availability of generating sources that can be dispatched to meet the constantly changing customer demands. In the Newfoundland context, while wind offers the opportunity to displace a portion of the oil-fired energy produced at the Holyrood Thermal Generating Station on the Island of Newfoundland, no amount of wind capacity could displace the entire facility without significant investments in other (most likely fossil-fueled) dispatchable sources.

The focus of this report however, is to identify the factors that exist to influence the ultimate penetration of wind energy as it relates to the ability of the Island System to absorb the capacity particularly within periods of lighter load. As more and more intermittent and non-dispatchable capacity is added to the system, there comes a point at which the ability to maintain stability and acceptable voltages throughout the system is compromised. As well, there is an increased risk of spilling during high inflow periods as hydraulic production is reduced to accept non-dispatchable production.

This report provides a high-level overview of the potential impacts of non-dispatchable resources, and in particular wind energy, on the bulk electric system on the Island of Newfoundland. It identifies an order of magnitude quantity of wind generation capacity that may be integrated into the existing Island grid without adversely impacting the security of the system. It also assesses the manner in which non-dispatchable generation can cause the unintended result of displacing existing hydroelectric generation and thereby not fully achieving the benefit of displacing fossil fuel consumption at Holyrood. To maintain the general nature of these findings, no attempt has been made to incorporate site-specific limitations. Every project that is contemplated, wind or otherwise, must be evaluated in the context of the general concerns described above, as well as issues specific to the site.

2. Background and Experience Elsewhere

Wind generation is a rapidly growing technology and by the end of 2002, there were approximately 31000 MW of installed capacity worldwide. In 2002 alone almost 7000 MW of new wind generation was installed with the majority of the growth (almost 6000 MW) being in European countries. In North America, there was approximately 4900 MW installed wind capacity at the end of 2002 of which 450 MW was added that year. Recent estimates put Canada's installed wind generation capacity at 371 MW, with the majority in Alberta (201 MW) and Quebec (113 MW).

There are a number of reasons for the higher installed capacity of wind generation in several European countries including the fact that the technology is more mature as the majority of manufacturing companies are located in Europe resulting in a higher level of experience and acceptance. Many European countries also have strong bilateral interconnections with neighboring jurisdictions which are beneficial if not critical in coping with the variability of large amounts of wind generation in a technically sound and economic manner.

With very few exceptions most jurisdictions involved in large-scale wind production are targeting a penetration level of 10 –15% of system peak load. A number of jurisdictions such as Ireland, Spain and the New York system in the United States have conducted studies and produced extensive reports detailing the issues associated with the integration of wind generation into their particular systems. For the most part the studies which are readily available concern large interconnected systems and their findings, while generally applicable, do not address all of the concerns present on a relatively small, predominately hydroelectric based isolated system as exists on the Island of Newfoundland. The isolated nature of the system results in it being characterized as "electrically weak".

The system with the most similar circumstances is the Tasmanian system in Australia which is also predominantly hydroelectric, and currently operates isolated from the Australian grid. Tasmania currently has a small amount of wind generation, however there is potential for further development and the utility has completed extensive studies of expansion alternatives. The expansion plans include a HVDC interconnection to the Australian main land but the resultant system will still be relatively electrically weak with characteristics similar to those of the Newfoundland system. Frequency and voltage control are issues with this system as is the potential for reservoir spill. The Tasmanian studies show that utilizing conventional wind technology, while maintaining an efficient operation of the hydroelectric resource, it is possible to obtain wind penetration of approximately 8% of the system peak load. Based on the similarities between the Tasmanian and Newfoundland systems, the penetration levels estimated for Tasmania should be indicative of levels that may be expected on the Newfoundland system. However, as the Tasmanian system operates with a higher load factor, one would suspect that the Newfoundland system, with its lower summer loads, would support a somewhat lower level of wind penetration.

3. Existing System Capability

Table 3-1 provides a summary of the existing capacity and energy capability of the Island System. Hydro is the prime supplier of electrical energy, accounting for 80% of the Island's net capacity. The remaining capacity is supplied by Newfoundland Power Inc. Limited (8%), Corner Brook Pulp and Paper Limited (6%), Abitibi Consolidated Inc. (3%), and by Hydro through contracts with four Non-Utility Generators (3%). It is important to note that, unlike most other North American jurisdictions, there are no interconnections with power systems in Labrador or outside the Province. Accordingly, the island system must operate in a completely self-contained system, responding to internal changes without support from outside entities. This often introduces issues or concerns that may not be as pronounced in other larger systems.

Hydroelectric generating units account for 65% of the total existing Island net capacity and firm energy capability. The remaining net capacity comes from thermal resources and is made up of conventional steam, combustion turbine and diesel generating plants. Approximately 70% of the existing thermal capacity is located at the Holyrood Thermal Plant and is fired using heavy oil. The remaining capacity is located at smaller sites throughout the Island.

3.1. Holyrood Thermal Generating Station

The large thermal plant at Holyrood has a three-fold purpose. First, Holyrood is used to meet consumer demands during periods of high consumption. This is often referred to as its peaking role. Second, Holyrood supplements the energy capability of the hydro plants as inflows to the reservoirs vary and is an essential part of Hydro's supply portfolio. Third, Holyrood is used to support transmission voltages and security on the eastern portion of the grid. Having a Holyrood unit, or units, on-line and generating, even at modest amounts, is necessary to allow power from generating sources at Bay d'Espoir and west to be transferred to the east while maintaining acceptable system voltages and power quality to Hydro's customers.

Table 3-1

Island Capability	Net Capacity (MW)	Energy (GWh)	
		Firm	Average
Newfoundland & Labrador Hydro			
Bay D'Espoir	592.0	2234	2596
Upper Salmon	84.0	476	550
Hinds Lake	75.0	283	340
Cat Arm	127.0	605	704
Granite Canal	40.0	216	224
Paradise River	8.0	27	37
Snook's, Venam's & Roddickton Mini Hydros	1.3	5	7
TOTAL NLH HYDRO	927.3	3846	4458
Holyrood	465.5	2996	2996
Combustion Turbine	118.0	-	-
Hawke's Bay & St. Anthony Diesel	14.7	-	-
TOTAL NLH THERMAL	598.2	2996	2996
Newfoundland Power Inc.			
Hydro	94.6	323	424
Combustion Turbine	43.9	-	-
Diesel	7.0	-	-
TOTAL NP	145.5	323	424
Corner Brook Pulp and Paper Ltd.			
Hydro	121.9	785	865
Abitibi Consolidated Inc.			
Hydro	59.1	443	470
Non-Utility Generators			
Star Lake Hydro Partnership	15.0	93	141
Algonquin Power	4.0	14	16
Exploits River Partnership	32.1	110	137
CBP&P Co-generation	15.0	100	100
TOTAL NON-UTILITY	66.1	317	394
TOTAL EXISTING	**1918.1**	**8710**	**9607**

3.2. Existing Non-Dispatchable Resources

Approximately 350 MW, or 18% of the existing net capacity on the Island system is not directly controlled by Hydro, the power system operator. This includes 275 MW of customer owned hydroelectric capacity, 66 MW of non-utility generation capacity, and 9 MW of run-of-river hydroelectric capacity owned by Hydro. For the most part, the output from these facilities as described below is beyond the immediate control of Hydro.

- Corner Brook Pulp & Paper (CBK P&P) owns two hydroelectric plants and one co-generation plant. It operates its hydroelectric plants to minimize power purchase costs from Hydro. They are therefore non-dispatchable for power system requirements. However, the large hydroelectric plant at Deer Lake has a large reservoir and therefore the output of the plant is not directly related to inflow patterns and is generally constant. The co-generation plant is also non-dispatchable as its output is dependent on paper manufacturing requirements.

- Abitibi Consolidated Incorporated (ACI) owns three hydroelectric plants. It operates these plants to minimize spillage and to maintain a minimum output for its paper manufacturing process needs. Its two largest plants are run-of-river plants downstream of a large storage reservoir. Water is released from the reservoir by ACI to ensure a minimum output is maintained at the run-of-river plants. However, during periods of high inflows that occur for short durations of hours and days, the output of these run-of-river plants can increase substantially. This element of variable production is sold to Hydro but is non-dispatchable from a power system perspective.

- Newfoundland Power (NP) owns 23 hydroelectric plants. These plants are all small with relatively small storage reservoirs. NP operates its hydroelectric plants to minimize energy purchases from Hydro. The output from the hydroelectric plants is therefore variable with inflows. NP uses its small reservoirs to reduce spillage and to schedule operation of some units for daytime peak load periods. NP's hydroelectric plants, above a minimum output level, can generally be classified as non-dispatchable because they must be run in order to avoid water spillage.

- The remaining two small non-utility generators are single plant non-dispatchable operations. One plant is a run-of-river operation with no storage. The second plant has a reservoir but with installed capacity insufficient to provide dispatching of the generation. The reservoir enables the plant to operate continuously at its rated output with periodic spilling.

- Three of Hydro's hydroelectric plants are very small and non-dispatchable. One is a small run-of-river plant with inter-day dispatching capability during periods of low inflows.

As the power system operator, Hydro is responsible for dispatching its own larger generation resources to meet the variable demands of island electricity consumers while compensating for variability in the output of these energy sources it does not directly own or control.

4. Island Transmission System

The Island System (see Figure 4-1) consists of a 230 kV transmission backbone, with some parallel 138 kV and 66 kV transmission lines between 230 kV terminal stations. It also contains several 138 kV and 66 kV radial transmission networks.

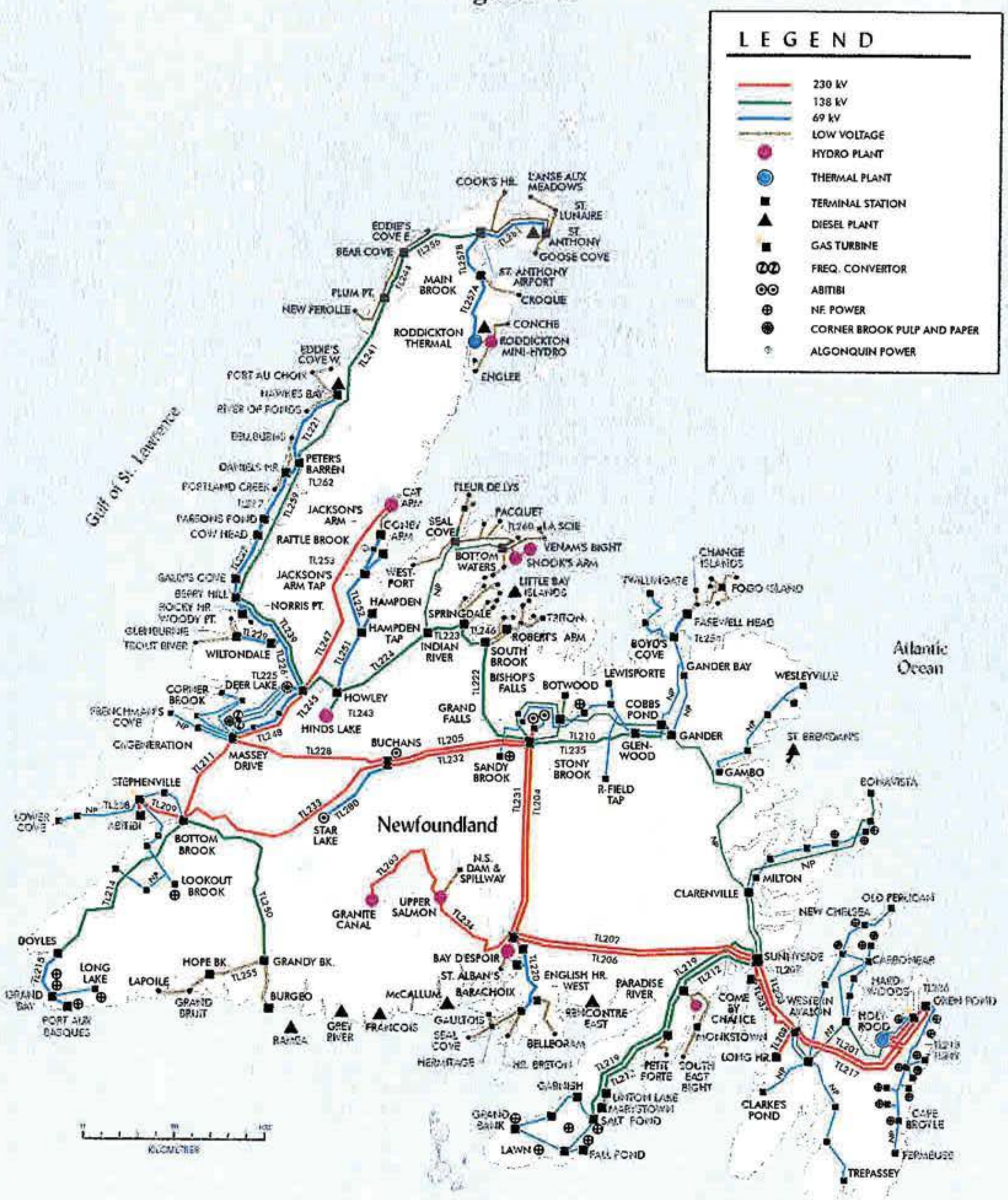
The 230 kV transmission system can itself be viewed as two regions with distinct characteristics. The Eastern/Avalon Peninsula region can be characterized as a heavily loaded transmission system where there is no significant hydroelectric generation. Accordingly, significant quantities of energy must be delivered from the western and central portions of the

Province through this region to the Avalon Peninsula. The transfer capability of this region is insufficient to meet the area load from October to May (and occasionally in June). For loads in this region in excess of 365 MW, the generation units at Holyrood are required to operate for voltage support and to maintain transmission line loadings below limits during line outages or contingency situations.

The region west of Bay d'Espoir (Western region) exhibits characteristics essentially opposite to the eastern portion. The western region has substantial transmission line capability to connect hydraulic generation to the grid, but significantly less concentrated load. Whereas the focus on the Eastern system is on keeping voltages high enough to meet customer requirements, the focus on the Western portion of the grid is most often on holding voltages down to an acceptable level during normal operation and contingency situations.

At the boundary of the two regions is the Bay d'Espoir complex that includes the Bay d'Espoir, Upper Salmon and Granite Canal generating stations. In addition to providing significant hydroelectric energy, Bay d'Espoir is the primary voltage control point for the Island System. As noted previously, the Holyrood Thermal Generating Station assists in voltage control in the Eastern region with the Cat Arm generating station providing some limited voltage control in the Western region.

Figure 4-1



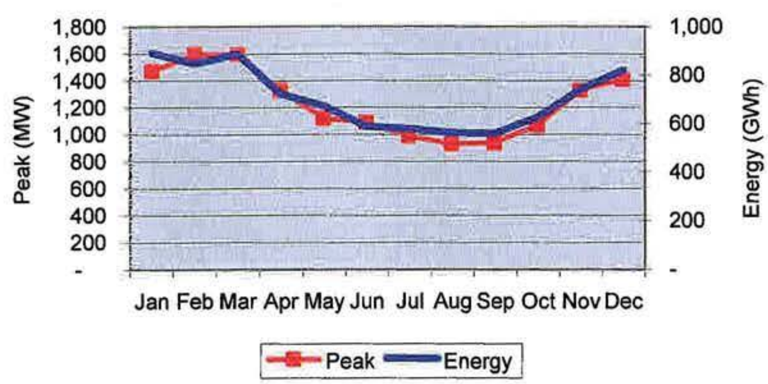
Island Generation and Transmission Grid

5. Island System Load

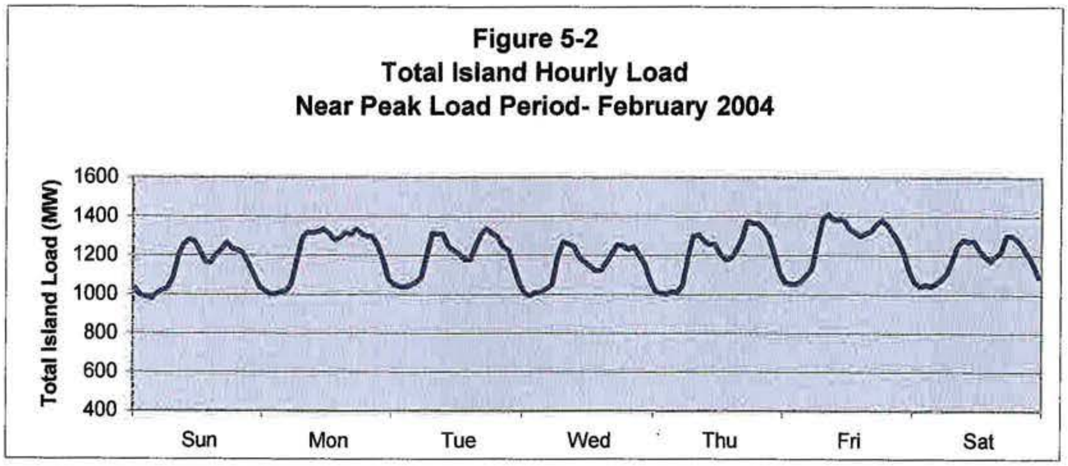
The load on the Island System is comprised of two main customer groupings: utility and industrial customers. The utility load refers to the electricity requirements for all residential and general service customer accounts on the Island System and presently accounts for some 70% of the total Island load. A significant driver of load within this group, and hence the overall system load, is the penetration of electric space and hot water heating.

Industrial customers account for the remaining 30% of the total Island load. In contrast to the utility load group, loads within the industrial group are generally constant throughout the year.

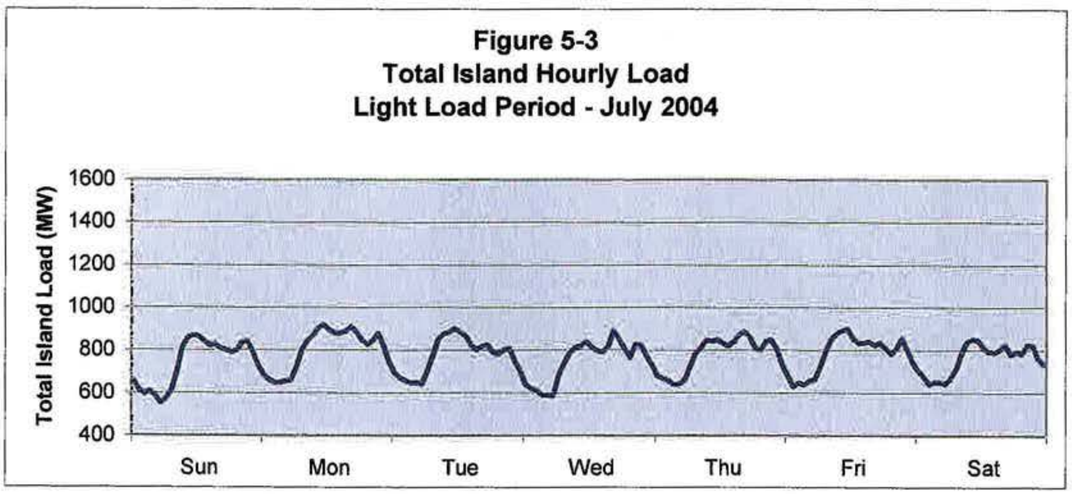
Figure 5-1
2003 Total Island Load - Monthly Distribution



These factors, combined with a lack of significant summer air-conditioning load, have resulted in a pronounced seasonal load shape for the Island System as is illustrated in the Figure 5-1. Owing to the presence of electric space and water heating, winter loads are significantly higher than summer loads with minimum winter loads seldom falling below 1000 MW and daytime peaks often in excess of 1300 MW (see Figure 5-2).



In contrast, low summer (nighttime) loads often fall to the 600 MW range with daytime highs seldom above 900 MW (see Figure 5-3).



6. Operation of the Island System

As the system operator for the Island, Hydro is responsible for insuring the quality of power supplied to the bulk system and delivered to our customers. In practice, this means dispatching Hydro generation and transmission resources to accommodate changes in customer load, customer generation, non-utility generation, and to prevent or limit system disturbances. As well, Hydro dispatches the system to minimize the cost of providing service while maintaining security.

Three key constraints that affect operation of the Island system are water management, frequency considerations and transmission limitations. Each of these constraints is affected by the integration of non-dispatchable generation be it hydroelectric, thermal, wind, etc.

6.1. Water Management

With no interconnections to the North American grid, the island system must operate in a fully self-sufficient manner. Accordingly, Hydro must maintain enough water in its reservoirs such that the storage, in combination with its purchase contracts and Holyrood generation, must be sufficient to meet all firm energy demands placed on the system for a repeat of the island's driest years. This translates into holding water in storage today for future needs up to three and a half years away. Holding too little water places the system in jeopardy of not being able to meet load requirements in a repeat dry sequence and would result in the curtailment of load and/or rotating blackouts. Holding too much water increases the likelihood that water may be spilled and lost to the system thereby increasing the overall cost to consumers through increased thermal production.

6.2. Frequency Considerations

Electrical systems in North America are designed to operate at an electrical frequency of 60 Hz. Deviations from 60 Hz can cause significant equipment damage and system degradation. Events such as tripping a generator, a large load, or a transmission line, can cause frequency deviations. The presence of interconnections prevalent with a national grid, largely mitigates the deviation for most contingencies by allowing a pooling of generation sources amongst participating utilities. Since Hydro operates an isolated system, no such sharing can take place. Instead, Hydro employs a load-shedding scheme to restore the balance between total generation and total load when system disturbances occur. The scheme trips blocks of load to the point where the imbalance caused by the disturbance is counteracted by the reduced load. To guard against unnecessarily large load sheds, Hydro limits the amount of generation from a single source at any time, depending upon the amount of load and generation on at the time.

6.3. Transmission Limitations

Transmission networks are required to transport electricity from generating sources to the bulk distribution points. Transmission networks have physical limitations on the amount of power that can be transferred. To move power through the network, reinforcement may be required along the way to ensure that the product at the receiving locations is within design limits and can meet customer requirements. Sometimes a generating unit or other means of compensation is required to supplement the transmission network so that more power can be delivered across the system.

Hydro, in its role as the system operator must balance these and other constraints in dispatching generation and transmission so as to supply the required load economically, reliably and safely.

7. Potential Impacts of Non-Dispatchable Generation

In light of the operational constraints that are inherent to the Island System, the addition of further quantities of non-dispatchable generation that can come on-line at any output level at any time may cause the following problems:

- Less load available for hydroelectric generation operation to limit spillage of water. During periods of high inflow to Hydro's reservoirs this may result in spillage of water because the water cannot be stored and produced later;

- Lower load levels available to generation required for transmission grid security. During light load periods the non-dispatchable generation may be supplying near the total system load. Depending on the location of this non-dispatchable generation in relation to the load on the system, it may cause the transmission network to be lightly loaded resulting in high voltages. The Bay d'Espoir units used to control the voltage cannot perform that function without sufficient loading. As well, under such a minimum loading condition an upset to the system such as a loss of load could trigger the system to shutdown (i.e. a system-wide blackout);

- Regional transmission loading concerns resulting in overvoltage conditions. Wind generation provides limited voltage control. If it displaces generation with voltage control capability, certain regions, particularly west of Bay d'Espoir, may experience high voltages that are difficult to control without added capital expense or a reduction in system security;

- Lower loading levels available to dispatchable generation used to economically share load. During off peak load hours, minimum amounts of dispatchable generation must be in service for voltage control and to be available in peak load hours. If there is less load available to these units this may force the larger units into inefficient loading zones. This is of particular concern for the Holyrood Thermal Generating Station units where there is an immediate and measurable financial consequence to inefficient loading; and

- A potential change in system inertia and governor regulation margin, especially with high penetration of non-dispatchable units vs. remaining generation.

The above issues represent technical limitations to the amount of non-dispatchable wind generation that may be absorbed into the Island System. In some cases a solution may be tied to a particular technical aspect, while in other cases, the impact may be measured in economic terms. For example, while Hydro may not be able to dispatch resources such as wind generation, the resource could be curtailed, i.e. removed from service when the system cannot absorb its energy thereby resulting in lost production from the resource and imposing an economic penalty to the wind energy producer. However, the identification of solutions to specific limitations is beyond the scope of this analysis as it would require considerable time and resource commitment and the detailed review of specific proposals.

The following sections present the results of analyses performed to identify an order-of-magnitude amount of additional non-dispatchable generation that may be brought onto the Island System without significantly impacting the secure and economic operation of the system, particularly as it relates to the increased risk of hydroelectric spill, and transmission constraints.

Amounts of non-dispatchable generation beyond these levels would require further and more detailed analysis of potential impacts to identify the full cost to Hydro and its rate-payers. In addition it must be realized that the levels identified herein apply to widely distributed resources connected to Hydro's bulk transmission system. Throughout this report, the attempt has been to avoid incorporating site-specific limitations so as to identify findings of a general nature. For any project contemplated, wind or otherwise, all must be evaluated in the context of the general concerns outlined herein, as well as issues specific to the site.

7.1. Impact on the Risk of Hydroelectric Spill

In order to determine the impact of additional quantities of non-dispatchable generation on the projected levels of spill, the decision support tool DSS VISTA used by Hydro's System Operations department was set up to test increments of non-dispatchable wind generation. VISTA is used by Hydro to assist the System Operations department in making weekly generation dispatch decisions. It is a numerical model of the major generating stations on the power systems, which optimizes the scheduling of the generators to provide the least cost energy supply for the upcoming week. This model is not ideal for assessing alternatives of future generation sources because its design focus is on the next week's production and it tends to understate the amount of spilled energy and the amount of production expected from Holyrood. However, it was the most readily available model for the timeframe permitted for this current analysis and will provide order of magnitude impacts.

Model Set-up

VISTA is set-up to model all the energy sources on the power system. It models in detail the large reservoirs of the 5 large hydro plants owned by Hydro, the Corner Brook Pulp and Paper (CBK P&P) hydro plant and Hydro's one small run-of-river plant. The remaining hydro plants are modeled as simple variable energy sources. The CBK P&P co-generation plant is modeled as a fixed output energy source with a specific monthly production pattern tied to the mill's paper production.

The Holyrood plant is modeled as a high cost energy source with monthly maximum and minimum output capabilities. The monthly minimum outputs were established based on the historic minimum number of units in operation each month. The minimum number of units in operation in each month reflects the requirement for load transfer into the Bay d'Espoir East transmission region.

For this exercise, wind generation was introduced to the model in a similar manner to the CBKP&P co-generation plant, as a fixed output energy source with a fixed output pattern. The pattern was refined to show hourly and monthly variations in production. The patterns were derived from an average of wind data measured in 1999 at four potential wind sites in the Province (Argentia, St. John's St. Lawrence, and Stephenville). The pattern was kept constant for all increments of wind generation injected into the system. Figures 7-1 and 7-2 show the resultant monthly allocation of wind turbine energy throughout the year and the typical daily load shape produced for wind turbine production. Wind farm nominal capacities were translated into annual energy values based upon simulated wind turbine production for wind data for 1997-2000 for the above-noted sites. The resultant average capacity factor of 34% represents the average expected for wind farms widely disbursed throughout the Island.

Figure 7-1
1999 Wind Energy Monthly Breakout

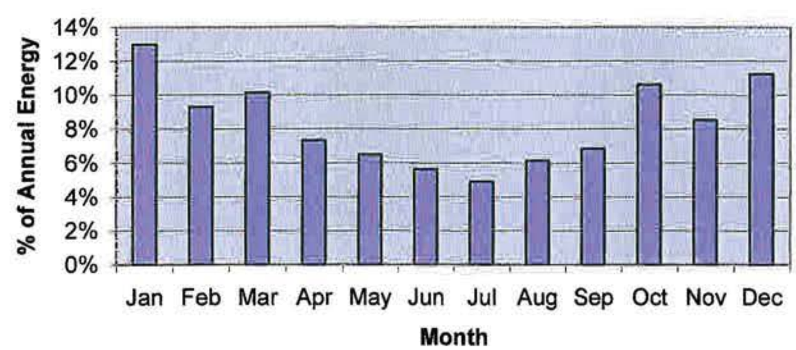
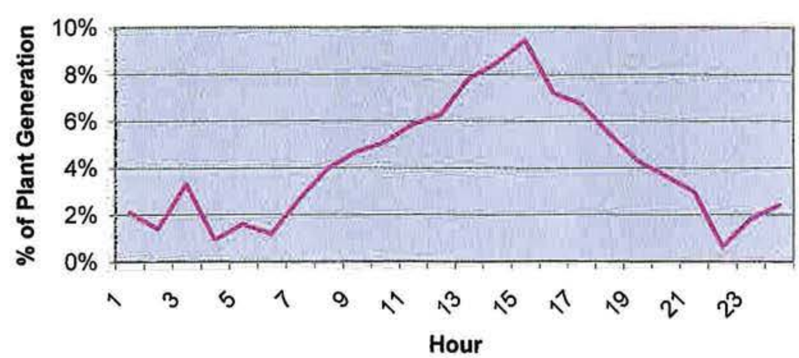


Figure 7-2
1999 Normalized Hourly Wind Generation Shape



Capacity factors for specific sites may be more or less than this average and would therefore impact on the results of the analysis with higher capacity factor installations (more energy per MW of installed wind capacity) yielding higher projected levels of spill, and vice versa.

For this exercise, the model was set-up to provide optimized production results for a 3-year sequence from 2005 to 2007, with the wind generation introduced in June of 2005. This allows the hydraulic reservoir planning to have been readied for this new non-dispatchable source to minimize spill in so far a possible and to model its impact for two full years, 2006 and 2007.

Cases Examined

The hydroelectric and thermal production for the 3-year sequence was optimized for 50 different historic inflow sequences so that all recorded inflow patterns and the corresponding optimum production was determined. Each run of the model for the 50 different inflow sequences produced a test case. The average Holyrood production and spilled energy was recorded for each case. Thirteen cases were established and run, including the base case existing system

Assumptions

The assumptions used in the analysis were:

1. No changes were made to the transmission network or to operating practices at Holyrood with respect to it's minimum loading requirement. Holyrood units were not operated below 60 MW from September to March and were not operated below 50 MW in April to June.
2. The wind generation was equally distributed across the island based on the measured wind data so that the pattern from any one site did not dominate the wind production.

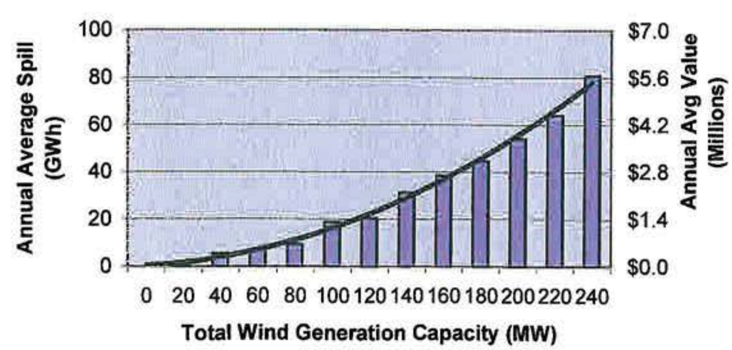
3. There were no changes in system generating capacity other than the addition of wind energy for the study period.
4. Spill from any facility, Hydro-owned or otherwise, was tracked. This was based upon the assumption that existing customers and non-utility generators would not spill on Hydro's behalf for the inclusion of wind turbine generation. Accordingly, any modeled spill from non-Hydro facilities due to wind turbine integration would ultimately be reflected in Hydro's spill.
5. Starting reservoir storages were assumed to be in the mid-range of those typically seen in January.

Results

The analysis was performed on an incremental basis, relative to the base case. Primary results tracked included the average spill from all reservoirs, converted to energy equivalents, and sourced to specific levels of wind energy penetration. Note that average spill represents the average energy lost to the Island System for the period January 2005 through to July 2007 inclusive. This is made up of a number of drier sequences of no or very low spill, as well as a number of wetter sequences with very high spill. The result is the average energy one would expect to spill over time with significant annual variations.

Figure 7-3 provides a summary of the average spill expected from the successive additions of 20 MW wind farms. As can be seen, the impact of non-dispatchable generation does not become pronounced until new injections

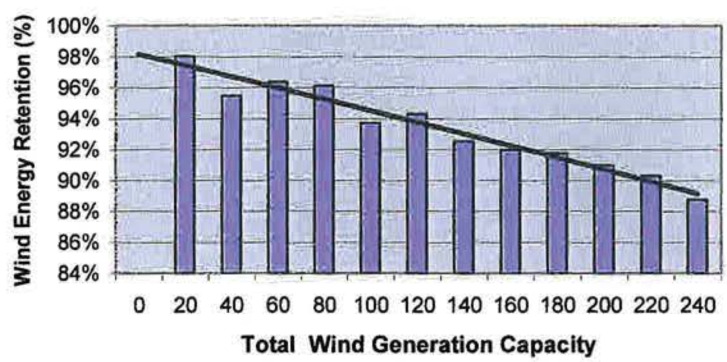
Figure 7-3
Wind Turbine Impacts on Spill



reach the 100 MW level where the impact of a 20 MW increase in wind capacity from 80 to 100 MW resulted in an approximate doubling of the expected level of spill from 9 to 19 GWh. At 100 MW and beyond, spill becomes even more significant, and rapidly increases with each increment in wind turbine installation. The figure also shows the value of the purchased energy that is ultimately spilled assuming a purchase price of 7 cents/kWh. While the analysis is very high-level, and the results are approximate, it does indicate the order of magnitude of potential spillage costs that can be expected with increasing levels of wind turbine penetration and that they can become quite significant.

In relation to the spill, Figure 7-4 provides a summary of the degree to which wind energy can be retained by the system. Again, by the time wind farms reach 100 MW of installed capacity, about 6% of the annual production will, on average, be of no benefit to electrical consumers as it will be lost to the system due to increased spill.

Figure 7-4
Wind Turbine Impacts on Spill



7.2. Power System Constraints

Power System constraints on the Island System can be grouped into two categories: frequency control and voltage control.

Frequency Control

Control of frequency on the Island System is the responsibility of Hydro's generating stations. At any point in time, Hydro must have sufficient generation on line to maintain nominal frequency during an ever-changing load requirement. Adding non-dispatchable generation to the Island system may result in fewer of Hydro's dispatchable generation resources being on line. As fewer generators are left to control system frequency, frequency excursions become magnified for the same change in load. A theoretical point can be reached where the slightest increase in load will cause the system to become unstable and collapse (i.e. system black-out). This raises the question as to the minimum level of Hydro's generation required to maintain control of the system frequency. A analysis has been conducted to determine the approximate minimum level.

Assumptions

The assumptions used in the analysis were:

- Hydro's generation must be able to return the system frequency to nominal following a sudden increase in load or a sudden decrease in load (load rejection);
- It is expected that frequency control is most difficult on a lightly loaded transmission system as there is little inertia (rotating generating equipment mass) on the system to arrest the rate of change in frequency;
- Wind turbines do not contribute to system inertia;
- The transmission system must be able to withstand the rejection of 70 MW of load (largest existing customer supply line);
- The system must be able to withstand the sudden step change in load of 10 MW (not a load ramp) equivalent to a trip of a Deer Lake Power Generator, a refiner motor, Paradise River trip, etc;
- System frequency must not fall below 59.6 Hz. Given that the first stage of the under frequency load shedding scheme incorporates relay settings at 59.5 Hz it is prudent not to encroach upon that level and risk the potential of false under frequency load trips and associated customer interruptions; and

- The frequency must not remain above 61.5 Hz for more than 25 seconds based upon Northeast Power Coordinating Council recommendations for wind turbine over frequency setting of 61.5 Hz for 30 seconds.

Dynamic simulations (stability studies) of the power system were completed using the Shaw Power Technologies Incorporated software package PSS/E. Results of the analysis indicate that the total system inertia must not fall below 3341 MW.sec including 2270 MW.sec of Hydro's generation. At this level of Hydro's generation, a minimum frequency of 59.6 Hz is achieved for 10 MW load steps. As well, 70 MW load rejections are expected to cause frequency increases to 62.9 Hz with a total time above 61.5 Hz of 23 seconds. It is expected that wind generators will maintain connection with the system for these events.

In comparison to transmission systems connected to the North American grid, the Island transmission system, with its large geographic area and relatively low and dispersed loads, is considered "electrically weak". Given that the transmission system contains relatively few synchronous generators and relatively long transmission circuits, short circuit levels, indicative of system strength, on the Island are quite low. As a result of low short circuit levels, a transmission line fault can be expected to cause a significant voltage dip on all buses within the region experiencing the faulted transmission line. Hydro has developed various protection schemes to clear faulted equipment in a timely manner to ensure stable operation of the transmission system post fault which minimizes customer disruption. However, the application of protection schemes incorporating feasible critical clearing times will not impact greatly on the minimum voltage levels during the fault. Given a minimum voltage setting of 85% for wind turbine generators, one can expect all wind generation in a region, Eastern or Western, to instantaneously trip for a transmission line fault in that region which may aggravate the stability of the system as a whole.

As noted in section 6.2, Hydro uses an under frequency load shedding scheme and limits the maximum unit size in service at any point in time to ensure that the system does not collapse following loss of a large generator. Given that all wind generation in a region will trip for a transmission line fault, it will be necessary to limit the total amount of wind generation in a region so that loss of wind generation due to a fault does not result in excessive frequency decay and the subsequent collapse of the entire system.

Voltage Control

Under normal conditions the transmission system is operated such that the voltage is maintained between 95% and 105% of nominal. During contingency events the transmission system voltage is permitted to vary between 90% and 110% of nominal prior to operator intervention. Following an event, operators will take steps (i.e. re-dispatch generation, switch equipment in/out of service, curtail load/production) to return the transmission system voltage to the 95% to 105% normal operating range.

The Eastern and Western regions have different voltage issues. The Eastern system is more heavily loaded and requires voltage support from Hydro's generators to keep voltage above the 95% minimum limit. The Western region is more lightly loaded and requires the assistance of Hydro's generators to keep voltages below the 105% maximum limit. The addition of wind generation on the Island must therefore be considered from two perspectives. First there are regional impacts and second there is the overall system impact. Analysis has been completed to determine the impact of wind generation on the voltage control capabilities of the system. It is expected that limiting conditions would occur during the summer light loading period.

Assumptions

The assumptions used in the analysis are:

- The study is conducted using an Island load of 650 MW that corresponds to the typical summer night load. This is a period where minimum levels of Hydro's generation are require to maintain voltages below 105%;
- Wind generators are VAR neutral to the system (i.e. have no voltage control);
- Wind generation is assumed to be widely distributed throughout the region under study to insure that localized, or site specific limitations do not impact on the study results;
- System voltages must stabilize below 110% prior to operator intervention for loss of a voltage control source (Bay d'Espoir, Cat Arm, Holyrood unit) or major load rejection (eg. Abitibi Consolidated Stephenville); and
- The magnitude of generation added must not adversely affect frequency control.

The analysis of the Eastern region indicates that the addition of wind generation in the region serves to unload heavily loaded transmission lines and thereby improves the regional voltage situation. In order to avoid excessive voltage levels at the boundary of the regions and system collapse due to the loss of a large block of generation, the total amount of wind generation east of Bay d'Espoir must be limited to approximately 90 MW.

The analysis of the Western region indicates that in order to avoid excessive over voltages following a system contingency, the total amount of wind generation west of Bay d'Espoir must be limited to approximately 70 MW. This limit is due in part to the fact that additional generation on the west coast of the province further unloads existing lightly loaded transmission lines and thereby exacerbates the problem of high voltage. To overcome high voltage levels additional Hydro dispatchable generation is required to be in service on the Western region for voltage control.

For the power system as a whole, and excluding any other constraints, the total installed wind generation should not exceed approximately 130 MW while maintaining the individual regional capacity limitations. That is to say, 70 MW of wind in the Western region would limit the Eastern region to a maximum of 60 MW, or conversely, 90 MW in the Eastern region would result in no more than 40 MW in the West. The reduction from the sum total of the two individual regions is attributed to the interrelationship between the regions. Any combination of dispersed wind generation would require additional study to refine these figures further.

8. Conclusions

The addition of further quantities of non-dispatchable resources to the Island System beyond what currently exists is expected to impose further limitations on the system with respect to the ability of Hydro to operate the system in a secure and economic manner which is in the overall interest of electricity consumers on the Island. Three specific key constraints that affect the operation of the Island system are water management, frequency considerations and transmission limitations. Unlike most other North American jurisdictions, these constraints are further magnified for the Island system due to the lack of an interconnection to other neighboring power systems. Accordingly, the Island system must operate as a completely self-contained system, responding to internal changes without support from outside entities.

Analyses designed to identify an order-of-magnitude amount of additional non-dispatchable wind generation that may be brought onto the Island System without significantly impacting the secure and economic operation of the system were focused on these constraints.

With respect to Hydro's ability to manage the hydroelectric resource on the Island, additional amounts of non-dispatchable wind generation up to 80 MW may be incorporated into the system with little risk of additional spill. Beyond this level, where the impact of a 20 MW increase in wind capacity from 80 to 100 MW resulted in an approximate doubling of the expected level of spill from 9 to 19 GWh on an average annual basis, spill becomes even more significant, and rapidly increases with each increment in wind turbine installation. To illustrate the economic value of this lost hydraulic energy capability, 19 GWh of energy at an assumed cost of 7 cents/kWh would be valued at approximately $1.3 million on an average annual basis.

With respect to just the system security limitations related to the ability of Hydro to maintain continuity of service, amounts of non-dispatchable wind generation up to 130 MW may

HYDRO
THE POWER OF COMMITMENT

be integrated into the system as a whole without significant technical performance repercussions. However, regional constraints further limit the distribution of this new non-dispatchable generation on the system west of Bay d'Espoir to no more than 70 MW, and to no more than 60 MW on the system east of Bay d'Espoir.

Based on the level of analyses performed, and taking into consideration each of the limiting factors it would appear at this time it would be prudent to set an upper limit of 80 MW of wind generation that could be incorporated into the Island System with few adverse effects. However, given the preliminary nature of this investigation, it would be prudent to further limit the initial quantities of wind generation into the system. Consideration should be given to a step-wise pattern of increased penetration levels over a number of years to gain direct operating experience with the technology and its integration into the Island system. This would allow Hydro to further define the opportunities and constraints associated with the resource without subjecting customers to undue expense or power quality issues. As well it would allow the industry to arrive at possible solutions which, along with the experience gained by Hydro, may permit penetration levels beyond those currently identified

Amounts of non-dispatchable generation, including wind, beyond these levels would require further and more detailed analysis of potential impacts to identify the full cost to Hydro and its rate-payers. In addition it must be clear that the levels identified herein apply to widely distributed resources connected to Hydro's bulk transmission system. To maintain the general nature of these findings, no attempt has been made to incorporate site-specific limitations. Every project that is contemplated, wind or otherwise, must be evaluated in the context of the general concerns described above, as well as issues specific to the site.