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July 13, 2016

The Board of Commissioners of Public Utilities
Prince Charles Building
120 Torbay Road, P.O. Box 21040
St. John's, NL A1A 5B2

Attention: **Ms. Cheryl Blundon**
Director Corporate Services & Board Secretary

Dear Ms. Blundon:

Re: Newfoundland and Labrador Hydro - the Board's Investigation and Hearing into Supply Issues and Power Outages on the Island Interconnected System – Nostradamus Upgrades Monthly Report

In accordance with item 2.1 of the Liberty Report Recommendations dated December 17, 2014, wherein Hydro is required to "provide the Board with monthly updates on the status of Nostradamus upgrades until the production model is fully in-service and shaken down", please find enclosed the original plus 12 copies of Hydro's report entitled *Accuracy of Nostradamus Load Forecasting at Newfoundland and Labrador Hydro Monthly Report: June 2016.*

We trust the foregoing is satisfactory. If you have any questions or comments, please contact the undersigned.

Yours truly,

NEWFOUNDLAND AND LABRADOR HYDRO

Kyle B. Tucker, M. Eng., P. Eng.
Manager, Regulatory Engineering

KT/bs

cc: Gerard Hayes – Newfoundland Power
Paul Coxworthy – Stewart McKelvey Stirling Scales
Sheryl Nisenbaum – Praxair Canada Inc.
Thomas Johnson – Consumer Advocate
Thomas O' Reilly – Cox & Palmer
Danny Dumaresque

ecc: Roberta Frampton Benefiel – Grand Riverkeeper Labrador

Accuracy of Nostradamus Load Forecasting at Newfoundland and Labrador Hydro

Monthly Report: June 2016

Newfoundland and Labrador Hydro

July 13, 2016

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1 NOSTRADAMUS LOAD FORECASTING

1.1 Nostradamus

Newfoundland and Labrador Hydro (Hydro) uses software called Nostradamus, by Ventyx, for short-term load forecasting with a time frame of seven days. "The Nostradamus Neural Network Forecasting system is a flexible neural network based forecasting tool developed specifically for utility demand forecasting. Unlike conventional computing processes, which are programmed, neural networks use sophisticated mathematical techniques to train a network of inputs and outputs. Neural networks recognize and learn the joint relationships (linear or non-linear) between the ranges of variables considered. Once the network learns these intricate relationships, this knowledge can then easily be extended to produce accurate forecasts." (Nostradamus User Guide, Release 8.2, Ventyx, an ABB Company, May 2014).

The Nostradamus model is trained using a sequence of continuous historic periods of hourly weather and demand data, then forecasts system demand using predictions of those same weather parameters for the next seven days.

1.2 Short-Term Load Forecasting

Hydro uses its short-term load forecast to manage the power system and ensure adequate generating resources are available to meet customer demand.

1.2.1 Utility Load

Hydro contracts Amec Foster Wheeler (Amec) to provide the weather parameters in the form of twice daily hourly weather forecasts for a seven-day period. At the same time as the weather forecast data are provided, Amec also provides recent observed data at the same locations. The forecast and actual data are automatically retrieved from Amec and input to the Nostradamus database.

Nostradamus can use a variety of weather parameters for forecasting as long as a historical record is available for training. Hydro currently uses: air temperature, wind speed, and cloud cover. Nostradamus can use each variable more than once, for example both the current and forecast air temperatures are used in forecasting load. Wind chill is not used explicitly as the neural network function of Nostradamus will form its own relationships between load, wind and temperature, which should be superior to the one formula used by Environment Canada to derive wind chill.

Weather data for four locations are used in Nostradamus: St. John's, Gander, Deer Lake, and Port aux Basques. Data from January 1, 2013 to December 31, 2015 are being used for training and verification purposes. The training and verification periods are selected to provide a sufficiently long period to ensure that a range of weather parameters are included, e.g., high and low temperatures, but short enough that the historic load is still representative of loads that can be expected in the future.

In addition to the weather and demand data, a parameter that indicates daylight hours each day is input to Nostradamus.

Demand data for the Avalon Peninsula alone and for the Island Interconnected System as a whole are input to Nostradamus automatically each hour. Only total utility load (conforming), Newfoundland Power's and Hydro's, is input in the Nostradamus model. Industrial load (non-conforming), which is not a function of weather, is forecast outside the Nostradamus program and added to the forecasts from Nostradamus to derive the total load forecast.

During the process of training the Nostradamus model, it creates separate submodels for weekdays, weekends and holidays to account for the variation in customer use of electricity. Nostradamus has separate holiday groups for statutory holidays and also for days that are known to have unusual loads, for instance the days between Christmas and New Year's and the school Easter break.

1.2.2 Industrial Load

Industrial load tends to be almost constant, as industrial processes are independent of weather. Under the current procedure, the power-on-order for each Industrial Customer, plus the expected owned generation from Corner Brook Pulp and Paper (CBPP), is used as the industrial load forecasts unless System Operations engineers modify the forecast based on some knowledge of customer loads, for instance a decrease due to reduced production at CBPP or a ramp up in the load expected at Vale. Engineers can change the expected load in one or more cells of a seven by twenty-four hour grid, or can change the default value to be used indefinitely.

1.2.3 Supply and Demand Status Reporting

The forecast peak reported to the Board of Commissioners of Public Utilities (the Board) on the daily Supply and Demand Status Report is the forecast peak as of 7:20 am. The weather forecast for the next seven days and the observed weather data for the previous day are input at approximately 5:00 am. Nostradamus is then run every hour of the day and the most recent forecast is available for reference by System Operations engineers and the Energy Control Centre operators for monitoring and managing available spinning reserves. The within day forecast updates are used by operators to decide if additional spinning reserve is required in advance of forecast system peaks.

1.3 Potential Sources of Variance

As with any forecasting there will be discrepancies between the forecast and the actual values. Typical sources of variance in the load forecasting are as follows:

- Differences in the industrial load forecast due to unexpected changes in customer loads;
- Inaccuracies in the weather forecast, particularly temperature, wind speed or cloud cover; and
- Non-uniform customer behaviour which results in unpredictability.

2 JUNE 2016 FORECAST ACCURACY

2.1 Description

Table 1 presents the daily forecast peak, the observed peak, and the available system capacity, as included in Hydro's daily Supply and Demand Status Reports submitted to the Board for each day in June 2016. The data are also presented in Figure 1. The actual peaks, as reported to the Board, varied from 738 MW on June 26 to 1072 MW on June 2.

The available capacity during the month was between 1245 MW on June 22 and 1475 MW on June 5. Reserves were sufficient throughout the period.

Table 2 presents error statistics for the peak forecasts during the month of June 2016. Figure 2 is a plot of the forecast and actual peaks, as shown in Figure 1, but with the addition of a bar chart showing the difference between the two data series. In both the tables and the figures, a positive error is an overestimate; a negative error is an underestimate.

In the month of June the forecast peak was in a range between 7.7% below the actual peak and 6.2% above the actual peak. On the best day the forecast peak was essentially the same as the actual peak; on the worst day it was 79 MW too low. On average, the forecast peak was 17 MW different than the actual peak, or 1.9%.

This report will further examine the forecast for June 13 when the forecast underestimated the peak by 79 MW or 7.7%, and June 15 when the forecast overestimated the peak by 50 MW, or by 6.2%.

Table 1 Jun 2016 Load Forecasting Data

Date	Forecast Peak, MW	Actual Peak, MW	Available Island Supply, MW	Forecast Reserve, MW
1-Jun-16	980	1007	1325	345
2-Jun-16	1040	1072	1345	305
3-Jun-16	950	953	1335	385
4-Jun-16	870	903	1470	600
5-Jun-16	900	919	1475	575
6-Jun-16	930	950	1320	390
7-Jun-16	880	854	1305	425
8-Jun-16	955	977	1315	360
9-Jun-16	1000	992	1300	300
10-Jun-16	940	955	1310	370
11-Jun-16	905	891	1300	395
12-Jun-16	800	797	1310	510
13-Jun-16	945	1024	1450	505
14-Jun-16	890	881	1425	535
15-Jun-16	855	805	1415	560
16-Jun-16	870	854	1440	570
17-Jun-16	915	903	1300	385
18-Jun-16	950	966	1310	360
19-Jun-16	790	816	1320	530
20-Jun-16	785	778	1320	535
21-Jun-16	780	783	1320	540
22-Jun-16	785	799	1245	460
23-Jun-16	785	777	1335	550
24-Jun-16	790	797	1325	535
25-Jun-16	745	754	1305	560
26-Jun-16	740	738	1325	585
27-Jun-16	790	789	1335	545
28-Jun-16	750	759	1365	615
29-Jun-16	790	793	1335	545
30-Jun-16	780	771	1415	635
Minimum	740	738	1245	300
Average	787	869	1347	484
Maximum	1040	1072	1475	635

Notes:
Forecast peak, available capacity and forecast reserve are rounded to the nearest 5 MW.
Forecast peak and available capacity presented is as reported to the Board. The forecast is updated hourly throughout the day for use in maintaining adequate generation reserves.
Forecast Reserve = Available Island Supply - (Forecast Peak - CBPP Interruptible Load (when applicable) - the impact of voltage

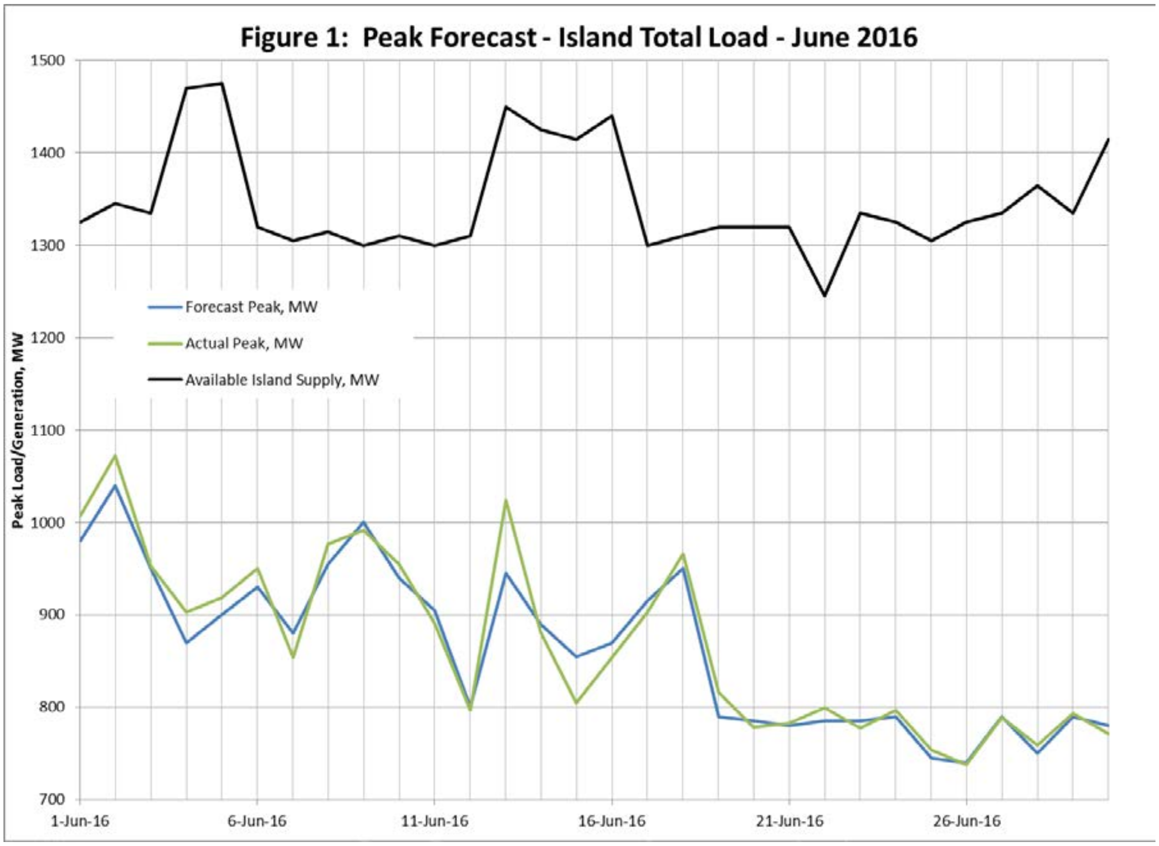


Figure 1: Peak Forecast - Island Total Load - June 2016
Peak Load/Generation, MW
1500
1400
1300
1200
1100
1000
900
800
700
Forecast Peak, MW
Actual Peak, MW
Available Island Supply, MW
1-Jun-16
6-Jun-16
11-Jun-16
16-Jun-16
21-Jun-16
26-Jun-16

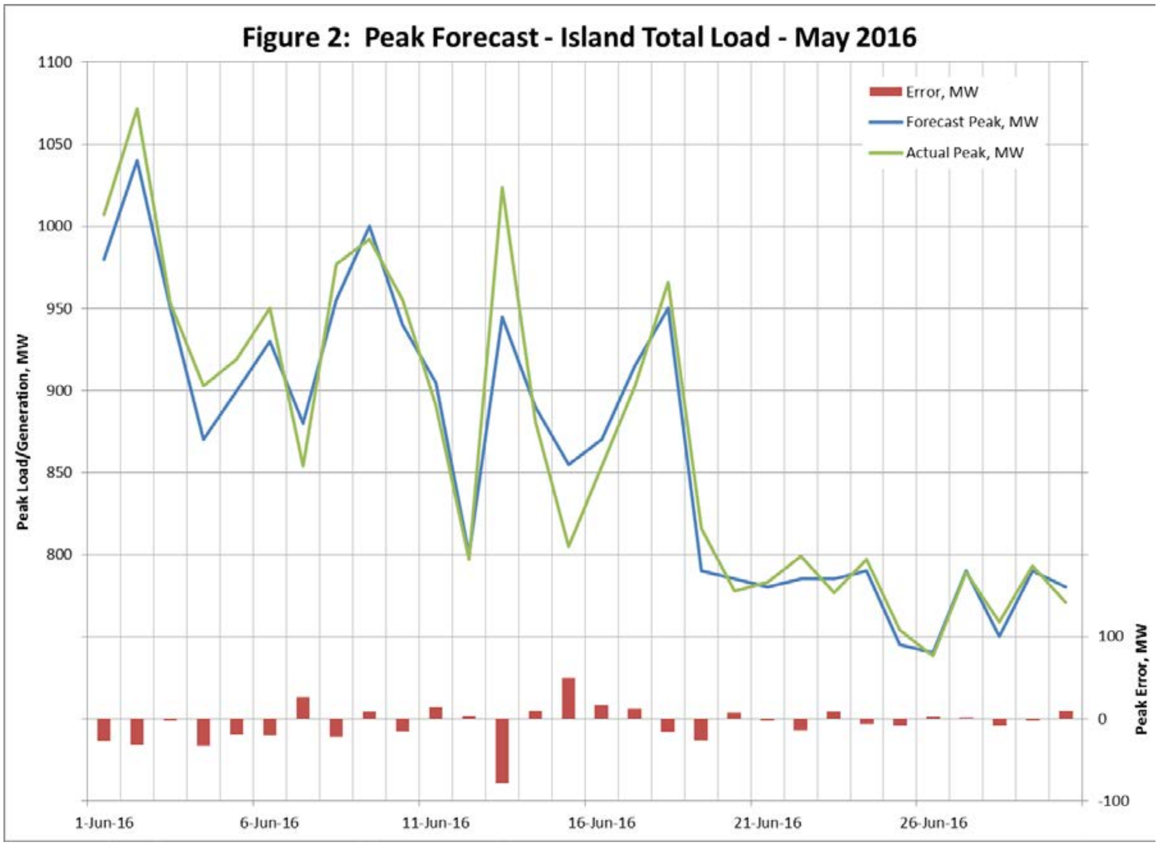
Table 2 Jun 2016 Analysis of Forecast Error

Date	Actual Peak, MW	Forecast Peak, MW	Error, MW	Absolute Error, MW	Percent Error	Absolute Percent Error	Actual/ Forecast
1-Jun-16	1007	980	-27	27	-2.7%	2.7%	-2.8%
2-Jun-16	1072	1040	-32	32	-3.0%	3.0%	-3.1%
3-Jun-16	953	950	-3	3	-0.3%	0.3%	-0.3%
4-Jun-16	903	870	-33	33	-3.7%	3.7%	-3.8%
5-Jun-16	919	900	-19	19	-2.1%	2.1%	-2.1%
6-Jun-16	950	930	-20	20	-2.1%	2.1%	-2.2%
7-Jun-16	854	880	26	26	3.0%	3.0%	3.0%
8-Jun-16	977	955	-22	22	-2.3%	2.3%	-2.3%
9-Jun-16	992	1000	8	8	0.8%	0.8%	0.8%
10-Jun-16	955	940	-15	15	-1.6%	1.6%	-1.6%
11-Jun-16	891	905	14	14	1.6%	1.6%	1.5%
12-Jun-16	797	800	3	3	0.4%	0.4%	0.4%
13-Jun-16	1024	945	-79	79	-7.7%	7.7%	-8.4%
14-Jun-16	881	890	9	9	1.0%	1.0%	1.0%
15-Jun-16	805	855	50	50	6.2%	6.2%	5.8%
16-Jun-16	854	870	16	16	1.9%	1.9%	1.8%
17-Jun-16	903	915	12	12	1.3%	1.3%	1.3%
18-Jun-16	966	950	-16	16	-1.7%	1.7%	-1.7%
19-Jun-16	816	790	-26	26	-3.2%	3.2%	-3.3%
20-Jun-16	778	785	7	7	0.9%	0.9%	0.9%
21-Jun-16	783	780	-3	3	-0.4%	0.4%	-0.4%
22-Jun-16	799	785	-14	14	-1.8%	1.8%	-1.8%
23-Jun-16	777	785	8	8	1.0%	1.0%	1.0%
24-Jun-16	797	790	-7	7	-0.9%	0.9%	-0.9%
25-Jun-16	754	745	-9	9	-1.2%	1.2%	-1.2%
26-Jun-16	738	740	2	2	0.3%	0.3%	0.3%
27-Jun-16	789	790	1	1	0.1%	0.1%	0.1%
28-Jun-16	759	750	-9	9	-1.2%	1.2%	-1.2%
29-Jun-16	793	790	-3	3	-0.4%	0.4%	-0.4%
30-Jun-16	771	780	9	9	1.2%	1.2%	1.2%
Minimum	738	740	-79	1	-7.7%	0.1%	-8.4%
Average	869	787	-6	17	-0.5%	1.9%	-0.6%
Maximum	1072	1040	50	79	6.2%	7.7%	5.8%

Notes:

Forecast peak is rounded to the nearest 5 MW

Forecast peak presented is as reported to the Board. The forecast is updated hourly throughout the day for use in maintaining adequate generation reserves.



2.2 Nostradamus Database Problem

On the morning of Saturday, June 25 a software issue prevented Nostradamus from producing updated forecasts. Energy Control Centre operators successfully managed generation and reserves through the long weekend without the updated forecasts. When Hydro's Energy Systems staff investigated the problem on Tuesday, June 28 (following the holiday), they found that a password for the database where the load and climate information is stored had expired. Without access to the database, Nostradamus was unable to produce forecasts. When the database was first set up, the programming should have been configured to prevent the password from expiring. When the programming was corrected and the password was reset, Nostradamus resumed operation. All observation data from the period when the model was out of service was automatically downloaded when the program restarted and was available for use.

Nostradamus has the ability to produce forecasts as if it were an earlier time, however it would use actual rather than forecast climate data, since forecast meteorologic data are not stored, but are replaced with each new forecast and then with observed data. Nostradamus therefore could not be made to produce exactly the forecasts that would have been available on June 25 through 28, had the model been working properly.

2.3 June 13, 2015

On June 13, the forecast peak at 7:20 am, as reported to the Board, was 945 MW; the actual reported peak was 1024 MW. The absolute difference was 79 MW, 7.7% of the actual. Figure 3 includes an hourly plot of the load forecast for June 13 as well as several charts which examine components of the load forecast to assist in determining the sources of the differences between actual and forecast loads.

Figure 3(a) shows the hourly distribution of the load forecast compared to the actual load. The forecast overestimated the load for the full 24-hour period. The forecast predicted a 6:00 pm peak of 943 MW; the peak was at 6:00 pm, but was 1022 MW.

Figure 3(b) shows the hourly distribution of the utility load forecast only, i.e., the load forecast with the industrial component removed. The utility forecast was worse than the total forecast for most of the day, so error in the industrial portion of the forecast reduced the total forecast error.

Figure 3(c) shows the actual temperature in St. John's compared to the forecast. With the exception of two or three hours in the afternoon, the actual temperate was consistently below the temperature forecast by up to four degrees. Since temperature has such a significant effect on the heating loads in the province, the error in the temperature likely explains much of the error in the load forecast.

Figure 3(d) shows the actual wind speed in St. John's compared to the forecast. For most of the day the wind forecast was quite accurate. The actual wind dropped below forecast in the evening after the peak, but during the peak the wind forecast was close to actual. The error in the wind speed forecast did not contribute significantly to the over forecast of the peak.

Figure 3(e) shows the actual cloud cover in St. John's compared to the forecast. The cloud cover was accurate – both the forecast and the actual cloud cover was 100% for most of the day.

The discrepancy between actual and forecast load for June 13 was likely primarily as a result of inaccuracies in the temperature forecast. The hourly within-day updates are used by Energy Control Centre operators to manage spinning reserve. By 1:30 pm the forecast peak was within 2% of the actual.


Figure 3 Accuracy Analysis - Jun 13, 2016
(a)
1100
1000
900
800
700
600
500
400
12:00 AM
4:00 AM
8:00 AM
12:00 PM
4:00 PM
8:00 PM
Total Load Forecast
Total Load Actual
(b)
Utility Load Forecast
Utility Load Actual
(c)
12
10
8
6
4
2
0
St. John's Temperature Forecast
St. John's Temperature Actual
(d)
45
40
35
30
25
20
15
10
5
0
St. John's Wind Speed Forecast
St. John's Wind Speed Actual
(e)
120
100
80
60
40
20
0
St. John's Cloud Cover Forecast
St. John's Cloud Cover Actual

2.4 June 15, 2015

On June 15, the forecast peak at 7:20 am, as reported to the Board, was 855 MW; the actual reported peak was 805 MW. The absolute difference was 50 MW, 6.2% of the actual.

Figure 4(a) shows the hourly distribution of the load forecast compared to the actual load. The forecast overestimated the load for most of the day, with the error seeming to increase as the day progressed. The forecast was for an 11:00 pm peak of 859 MW, the actual peak occurred at 11:00 am and was 796 MW.

Figure 4(b) shows the hourly distribution of the utility load forecast only, i.e., the load forecast with the industrial component removed. The utility forecast was significantly more accurate than the total forecast, indicating that it was error in the industrial forecast that caused the error in the total load forecast. The CBPP load averaged only 65 MW on June 15, compared to a forecast of 107 MW. At the time of the forecast and actual peaks, the CBPP load was less than 50 MW.

The discrepancy between actual and forecast load for June 15 was a result of the lower than forecast load from CBPP. The Energy Control Centre operators have a real time indication of the CBPP load so were well aware of the requirement for less generation than forecast.

Figure 4 Accuracy Analysis - Jun 15, 2016