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April 7, 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: March 2016.*

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

Yours truly,

NEWFOUNDLAND AND LABRADOR HYDRO

Jennifer M. Williams, P. Eng
General Manager, Hydro Production
JMW/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: March 2016

Newfoundland and Labrador Hydro

April 7, 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 April 1, 2012 to March 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. Preliminary training has been done on the Development system using data up to December 2015, but that has not been moved to Production yet.

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 Load Forecasting Improvements

Hydro has implemented the following changes to the load forecasting process since January 2014:

- Additional training for staff;

- Revised training and verification periods and additional quality control of the weather data, including the data from January 2014 which will improve the capability of the model to forecast loads at low temperatures;
- Adding weather parameters for cloud cover and daylight hours;
- Modifying actual demand data used in Nostradamus training to remove unusual system conditions such as significant outages;
- Changing forecasting processes so that Nostradamus forecasts only utility load, with industrial forecasts done separately;
- Changing forecasting process to allow adjustments to the generated forecast to account for unusual system conditions (e.g., to account for an abnormal system configuration that may result in more or less system losses); and
- Creation of new plots and tables showing the load forecast, spinning reserve, and available reserve, which are available on demand to System Operations staff for managing the system;
- Requirement for regular weather forecast accuracy reviewing and reporting from Amec; and
- Move to two weather forecasts per day and an update of observed weather data midday.
- Version 8.2.4 of the Nostradamus software was installed on Production in mid-August 2015. Implementation of the new version had no noticeable effect on the forecasts.

1.4 Potential Sources of Variance

Improvements made to the Nostradamus forecasting model and Hydro's processes for load forecasting have improved the reliability of the load forecasts. As with any forecasting, however, there will be ongoing 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 MARCH 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 March 2016. The data are also presented in Figure 1. The actual peaks, as reported to the Board, varied from 1164 MW on March 1 to 1548 MW on March 15.

The available capacity during the month was between 1655 MW on March 26 and 1955 MW on March 1. Reserves were sufficient throughout the period.

Table 2 presents error statistics for the peak forecasts during the month of March 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 March the forecast peak was in a range between 5.5% below the actual peak and 10.8% 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 126 MW too high. On average, the forecast peak was 39 MW different than the actual peak, or 2.9%.

The consistent overestimate of the load through March was, to a large extent, a function of the Kruger (CBPP) portion of the industrial load forecast. On many days in March, for some or all of the day, the CBPP load was significantly below the default forecast of 107 MW. The variance during the first few days of March was due to the lead being less than forecast demand at the paper mill. Later in the month Kruger experienced problems with its 66 KV lines into the Mill. Figure 3 shows the CBPP load forecast, the actual load, and the discrepancy. On some days the discrepancy was as much as 90 MW. Hydro's Energy Control Centre has a real time indication of the CBPP load and therefore operators were well aware of the lower than normal load and adjusted generation correspondingly. Because the load forecast is a total of the utility and industrial load forecasts, the result of the industrial load being lower than forecast is additional reserves available to the system.

Because the apparent error in the total forecast during these periods was a result of lower than forecast industrial load, it was not a reflection of the accuracy of the Nostradamus model which forecasts utility load only. Table 3 is a repeat of the statistics table for the days of the high discrepancies showing utility load only; the industrial load forecast and the industrial load have been removed. Of the nine days that were initially highlighted for review due to the extent of variance, the discrepancy in the utility forecast is only notable on three days, March 3, 5 and 11.

Table 1 March 2016 Load Forecasting Data

Date	Forecast Peak, MW	Actual Peak, MW	Available Island Supply, MW	Forecast Reserve, MW
1-Mar-16	1290	1164	1955	760
2-Mar-16	1400	1310	1925	621
3-Mar-16	1340	1269	1940	696
4-Mar-16	1490	1469	1945	552
5-Mar-16	1405	1486	1920	611
6-Mar-16	1380	1347	1930	646
7-Mar-16	1475	1399	1900	522
8-Mar-16	1465	1448	1905	537
9-Mar-16	1585	1514	1900	414
10-Mar-16	1455	1384	1915	557
11-Mar-16	1540	1457	1880	438
12-Mar-16	1415	1389	1905	587
13-Mar-16	1355	1385	1900	641
14-Mar-16	1480	1482	1930	547
15-Mar-16	1550	1548	1925	473
16-Mar-16	1425	1416	1890	562
17-Mar-16	1335	1297	1895	656
18-Mar-16	1415	1393	1895	577
19-Mar-16	1295	1307	1910	710
20-Mar-16	1405	1376	1925	616
21-Mar-16	1485	1467	1905	517
22-Mar-16	1435	1408	1935	597
23-Mar-16	1540	1540	1920	478
24-Mar-16	1580	1498	1910	428
25-Mar-16	1390	1375	1775	481
26-Mar-16	1330	1267	1655	421
27-Mar-16	1325	1302	1805	575
28-Mar-16	1315	1305	1855	635
29-Mar-16	1245	1232	1890	740
30-Mar-16	1295	1300	1850	650
31-Mar-16	1290	1296	1805	530
Minimum	1245	1164	1655	414
Average	1411	1382	1890	573
Maximum	1585	1548	1955	760

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 reduction).

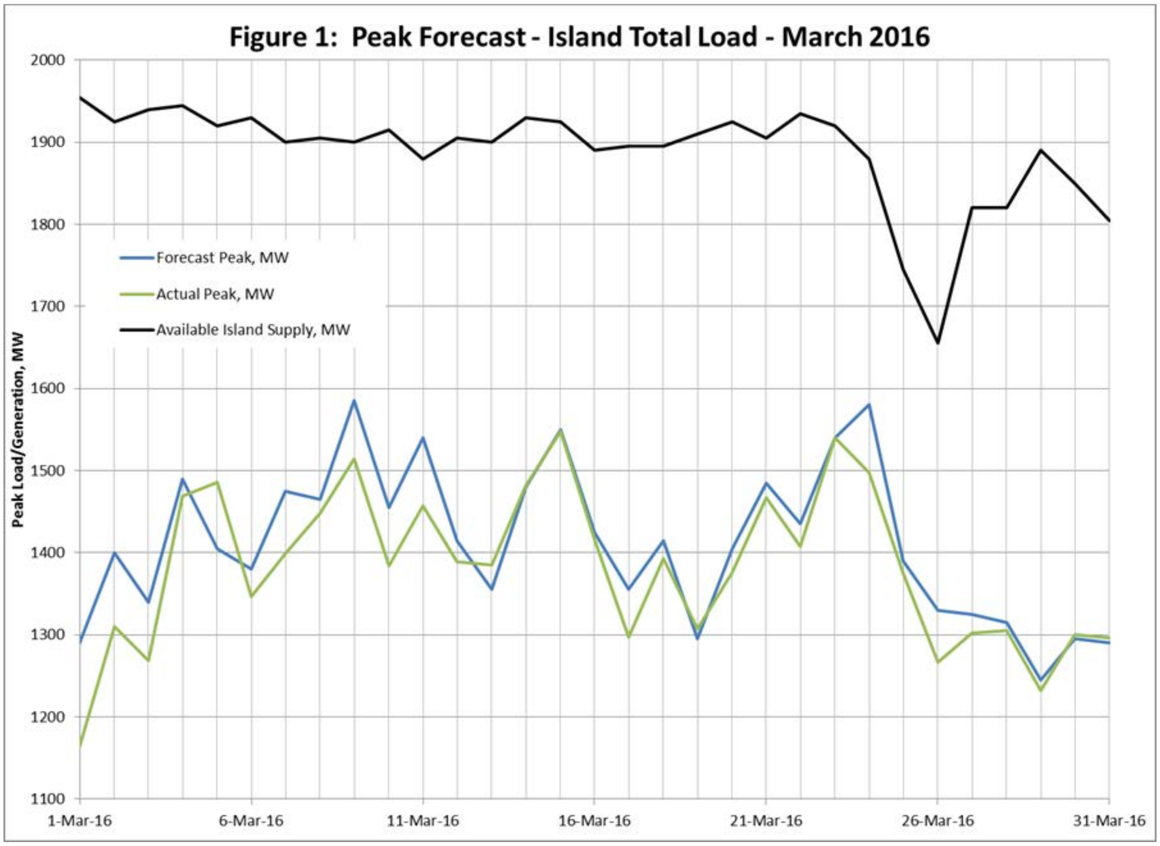


Figure 1: Peak Forecast - Island Total Load - March 2016
Peak Load/Generation, MW
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
Forecast Peak, MW
Actual Peak, MW
Available Island Supply, MW
1-Mar-16
6-Mar-16
11-Mar-16
16-Mar-16
21-Mar-16
26-Mar-16
31-Mar-16

Table 2 March 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-Mar-16	1164	1290	126	126	10.8%	10.8%	9.8%
2-Mar-16	1310	1400	90	90	6.9%	6.9%	6.4%
3-Mar-16	1269	1340	71	71	5.6%	5.6%	5.3%
4-Mar-16	1469	1490	21	21	1.4%	1.4%	1.4%
5-Mar-16	1486	1405	-81	81	-5.5%	5.5%	-5.8%
6-Mar-16	1347	1380	33	33	2.4%	2.4%	2.4%
7-Mar-16	1399	1475	76	76	5.4%	5.4%	5.2%
8-Mar-16	1448	1465	17	17	1.2%	1.2%	1.2%
9-Mar-16	1514	1585	71	71	4.7%	4.7%	4.5%
10-Mar-16	1384	1455	71	71	5.1%	5.1%	4.9%
11-Mar-16	1457	1540	83	83	5.7%	5.7%	5.4%
12-Mar-16	1389	1415	26	26	1.9%	1.9%	1.8%
13-Mar-16	1385	1355	-30	30	-2.2%	2.2%	-2.2%
14-Mar-16	1482	1480	-2	2	-0.1%	0.1%	-0.1%
15-Mar-16	1548	1550	2	2	0.1%	0.1%	0.1%
16-Mar-16	1416	1425	9	9	0.6%	0.6%	0.6%
17-Mar-16	1297	1335	38	38	2.9%	2.9%	2.8%
18-Mar-16	1393	1415	22	22	1.6%	1.6%	1.6%
19-Mar-16	1307	1295	-12	12	-0.9%	0.9%	-0.9%
20-Mar-16	1376	1405	29	29	2.1%	2.1%	2.1%
21-Mar-16	1467	1485	18	18	1.2%	1.2%	1.2%
22-Mar-16	1408	1435	27	27	1.9%	1.9%	1.9%
23-Mar-16	1540	1540	0	0	0.0%	0.0%	0.0%
24-Mar-16	1498	1580	82	82	5.5%	5.5%	5.2%
25-Mar-16	1375	1390	15	15	1.1%	1.1%	1.1%
26-Mar-16	1267	1330	63	63	5.0%	5.0%	4.7%
27-Mar-16	1302	1325	23	23	1.8%	1.8%	1.7%
28-Mar-16	1305	1315	10	10	0.8%	0.8%	0.8%
29-Mar-16	1232	1245	13	13	1.1%	1.1%	1.0%
30-Mar-16	1300	1295	-5	5	-0.4%	0.4%	-0.4%
31-Mar-16	1296	1290	-6	6	-0.5%	0.5%	-0.5%
Minimum	1164	1245	-81	0	-5.5%	0.0%	-5.8%
Average	1384	1415	30	39	2.3%	2.9%	2.1%
Maximum	1548	1585	126	126	10.8%	10.8%	9.8%

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.

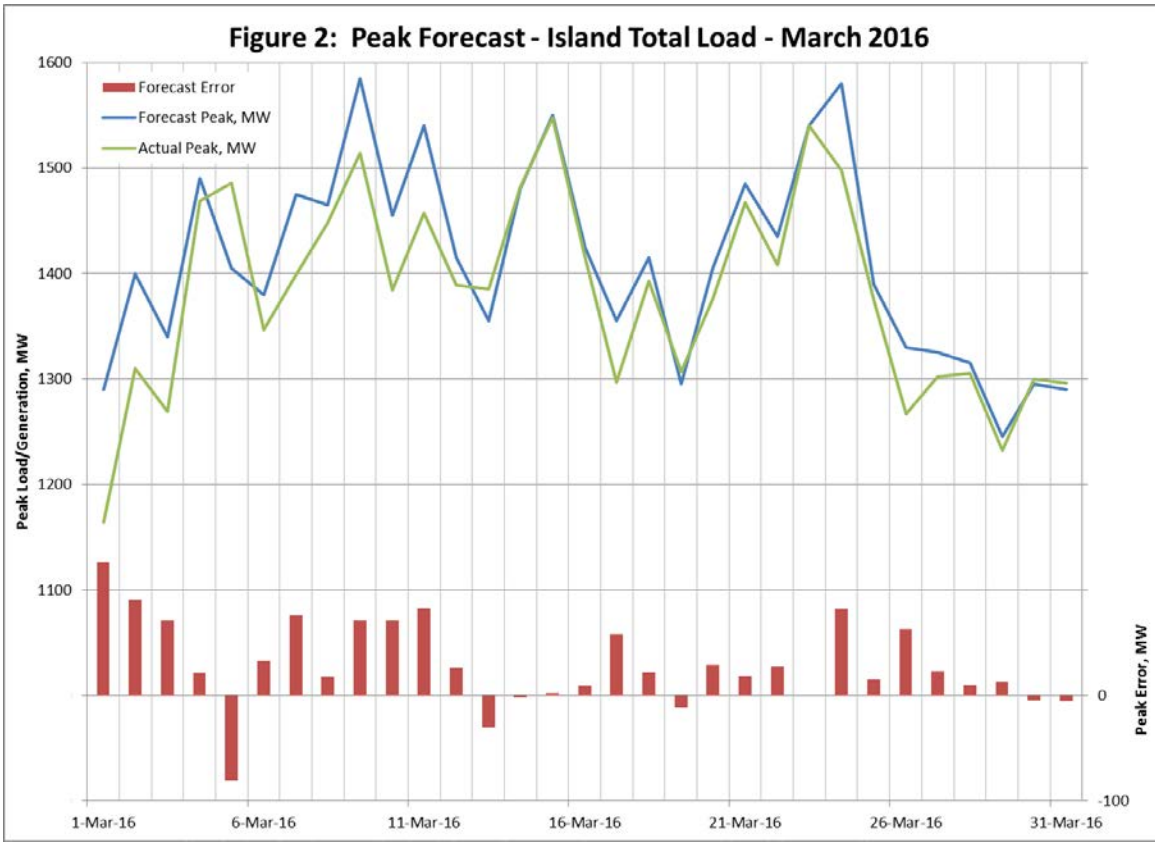


Figure 2: Peak Forecast - Island Total Load - March 2016
Forecast Error
Forecast Peak, MW
Actual Peak, MW
Peak Load/Generation, MW
Peak Error, MW
1600
1500
1400
1300
1200
1100
0
-100
1-Mar-16
6-Mar-16
11-Mar-16
16-Mar-16
21-Mar-16
26-Mar-16
31-Mar-16

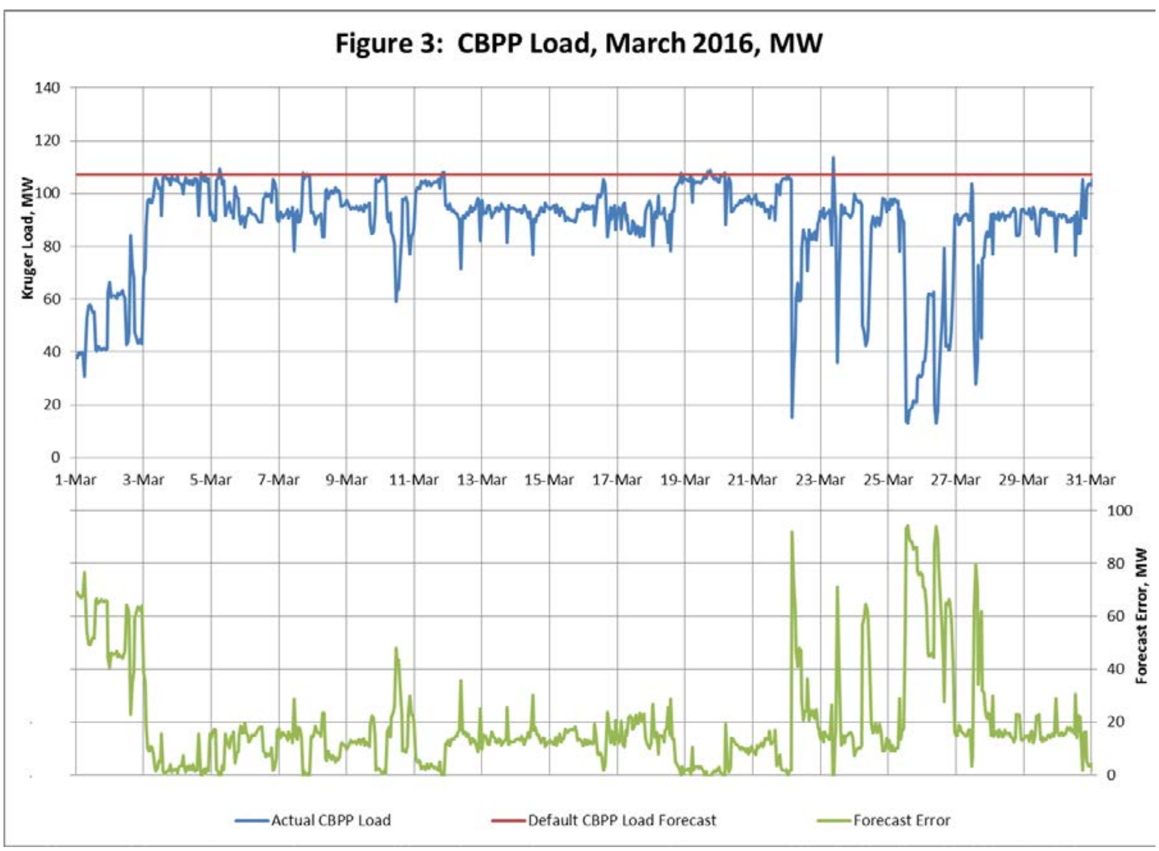


Figure 3: CBPP Load, March 2016, MW
Kruger Load, MW
Forecast Error, MW
140
120
100
80
60
40
20
0
1-Mar
3-Mar
5-Mar
7-Mar
9-Mar
11-Mar
13-Mar
15-Mar
17-Mar
19-Mar
21-Mar
23-Mar
25-Mar
27-Mar
29-Mar
31-Mar
Actual CBPP Load
Default CBPP Load Forecast
Forecast Error

Table 3 March 2016 Analysis of Utility Forecast Error

Date	Actual Peak, MW	Forecast Peak, MW	Error, MW	Absolute Error, MW	Percent Error	Absolute Percent Error	Actual/ Forecast
1-Mar-16	1079	1125	46	46	4.3%	4.3%	-4.3%
2-Mar-16	1189	1235	46	46	3.9%	3.9%	-3.9%
3-Mar-16	1110	1175	65	65	5.9%	5.9%	-5.9%
5-Mar-16	1333	1240	-93	93	-7.0%	7.0%	7.0%
7-Mar-16	1250	1310	60	60	4.8%	4.8%	-4.8%
10-Mar-16	1243	1287	44	44	3.5%	3.5%	-3.5%
11-Mar-16	1296	1377	81	81	6.3%	6.3%	-6.3%
24-Mar-16	1397	1416	19	19	1.4%	1.4%	-1.4%
26-Mar-16	1147	1164	17	17	1.5%	1.5%	-1.5%

2.2 Data Adjustment

On March 26, there was a brief disruption in data from the Bay d'Espoir Generating Station that resulted in an incorrect load being input into Nostradamus for 9:00 pm. This erroneous data point led to an incorrect forecast value for the following hour but this did not have any impact on system operation. The erroneous data point was corrected in the database by substitution of an interpolated value between 8:00 pm and 10:00 pm. The adjustment is made to the Nostradamus data so that in the future, when March 2016 data are used in training the forecasting model, Nostradamus will use a value that is not affected by the data error.

2.3 March 3, 2015

On March 3, the forecast peak at 7:20 am, as reported to the Board, was 1340 MW; the actual reported peak was 1269 MW. The absolute difference was 71 MW, 5.6% of the actual. Figure 4 includes an hourly plot of the load forecast for March 3 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 4(a) shows the hourly distribution of the load forecast compared to the actual load. The forecast overestimated both the morning and afternoon peak, but understated the load for the period in between peaks. The load shape was unusual in that the load did not vary much - the morning and afternoon peaks were little higher than the rest of the day. The maximum load occurred late in the day, at 8:45 pm. The forecast accurately predicted the time of the peak, but overestimated the value.

Figure 4(b) shows the hourly distribution of the utility load forecast only, i.e., the load forecast with the industrial component removed. The Kruger load returned to normal in the early hours of March 3 and averaged 104 MW for the second half of the day, so the overestimate discussed in Section 2.1 was not a factor in the error on this day. The error in the utility load forecast was similar to the error in the total forecast.

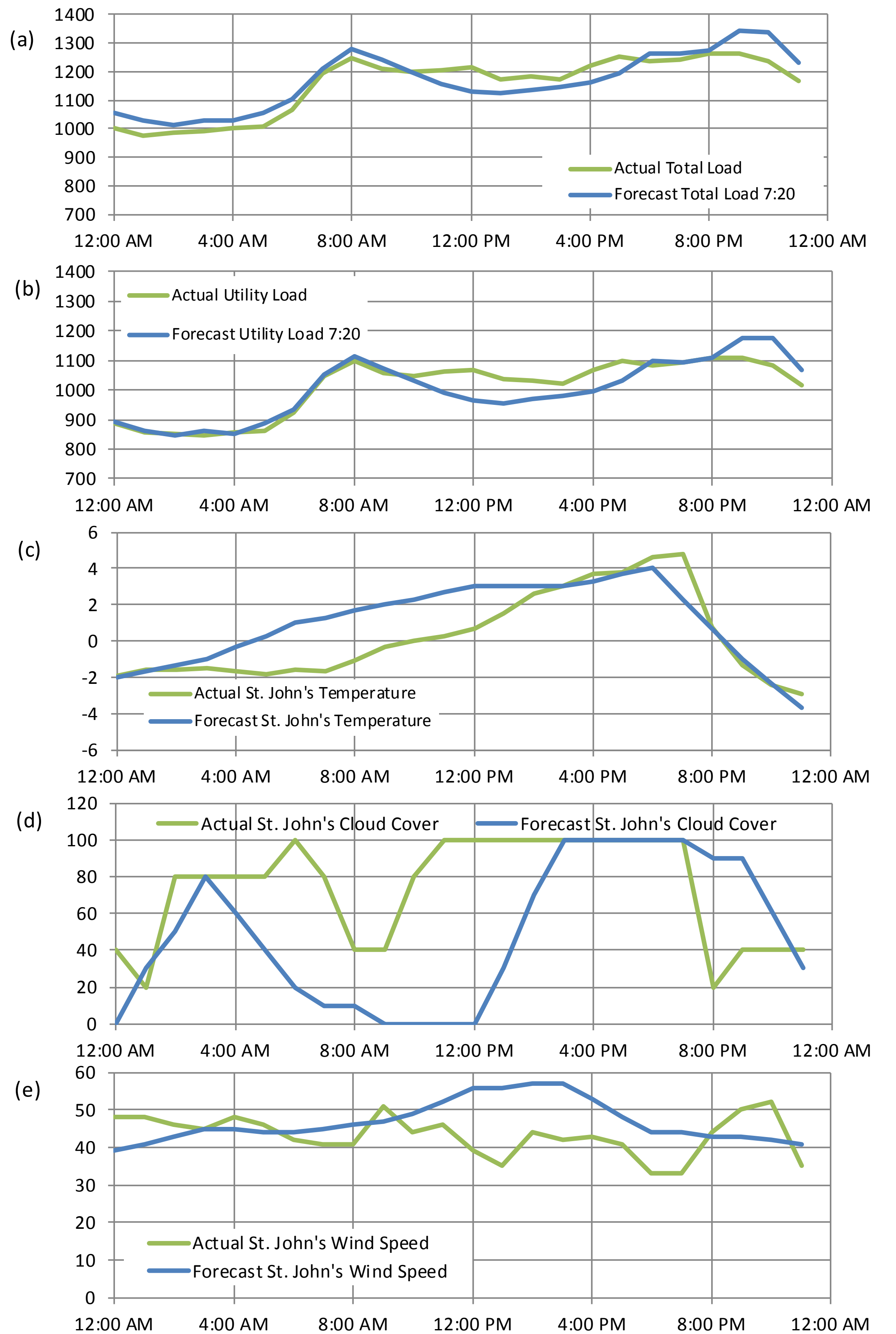
Figure 4(c) shows the actual temperature in St. John's compared to the forecast. Although Nostradamus uses weather data at four sites, the weather in St. John's tends to have the largest effect because of the concentration of population in St. John's. The actual temperature was lower than forecast in the morning and early afternoon and then on forecast or somewhat higher in the later afternoon and evening. At the time of the peak the forecast was accurate so error in the temperature forecast did not contribute to the error in the load forecast. The day did have an unusual temperature trend with the peak temperature occurring at 7 pm, which may have limited the accuracy of the load forecast.

Figure 4(d) shows the actual cloud cover in St. John's compared to the forecast. The weather was generally cloudier than forecast for most of the day. By the time of the peak it would have been dark, so cloud cover should not have affected the accuracy of the late day peak.

Figure 4(e) shows the actual wind speed in St. John's compared to the forecast. For most of the day the actual wind speed was lower than predicted, but it was higher than predicted at the time of the peak, which would have led to a higher load.

The discrepancy between actual and forecast load for March 3 was likely a result of Nostradamus's limited database of dates with late day temperature and load peaks. By midafternoon, the forecast had improved and was 2% of the actual. The hourly within-day updates are used by Energy Control Centre operators to manage spinning reserve. An overestimate of the peak results in more than enough spinning reserve.

Figure 4 Accuracy Analysis - March 3, 2015



2.4 March 5, 2015

On March 5, the forecast peak at 7:20 am, as reported to the Board, was 1405 MW; the actual reported peak was 1486 MW. The absolute difference was 81 MW, 5.5% of the actual. Figure 5 includes an hourly plot of the load forecast for March 5 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 5(a) shows the hourly distribution of the load forecast compared to the actual load. As with March 3, the load was quite flat throughout the day. The actual load was higher than forecast from 9:00 am until approximately 9:00 pm. The forecast predicted a 6:00 pm peak of 1406 MW. The actual hourly peak was at shortly before 5:00 pm, and was 1486 MW.

Figure 5(b) shows the hourly distribution of the utility load forecast only, i.e., the load forecast with the industrial component removed. On March 5 the Kruger load averaged about 12 MW lower than forecast, but this would lead to an overestimate of the load, not an underestimate. The error in the industrial load forecast did not contribute to the error in the total load forecast.

Figure 5(c) shows the actual temperature in St. John’s compared to the forecast. Although Nostradamus uses weather data at four sites, the weather in St. John’s tends to have the largest effect because of the concentration of population in St. John’s. The actual temperature was up to 4 degree C lower than forecast during the afternoon and evening, and was approximately 3 degrees C lower than forecast at the time of the peak which likely contributed to the underestimate of the load. In addition, the temperature trend for the day was unusual, with the peak temperature for the day happening at 11:00 pm. Nostradamus would have fewer data points in its database for predicting load during this type of sequence.

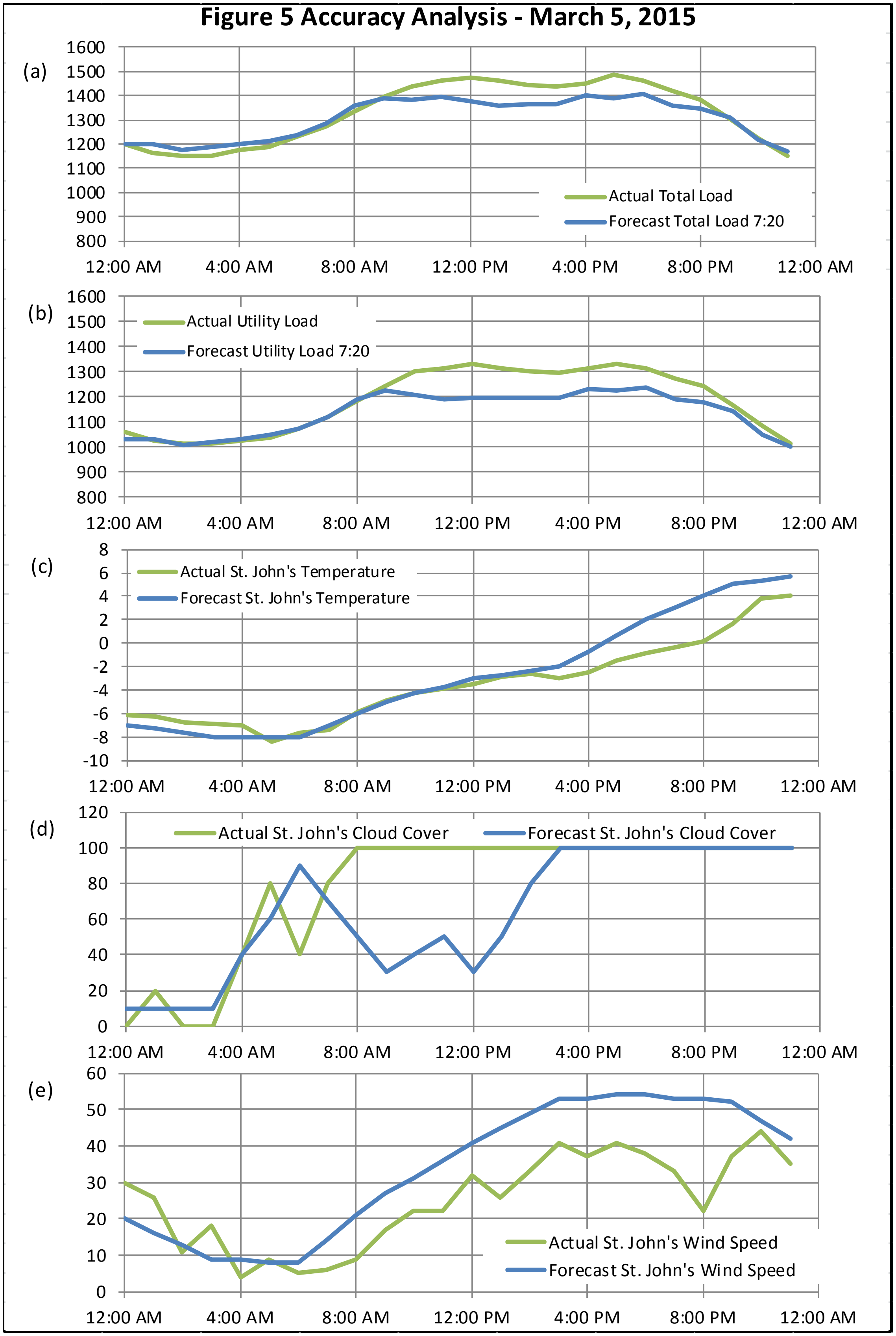


Figure 5 Accuracy Analysis - March 5, 2015
(a)
Actual Total Load
Forecast Total Load 7:20
(b)
Actual Utility Load
Forecast Utility Load 7:20
(c)
Actual St. John's Temperature
Forecast St. John's Temperature
(d)
Actual St. John's Cloud Cover
Forecast St. John's Cloud Cover
(e)
Actual St. John's Wind Speed
Forecast St. John's Wind Speed
12:00 AM
4:00 AM
8:00 AM
12:00 PM
4:00 PM
8:00 PM
12:00 AM

Figure 5(d) shows the actual cloud cover in St. John's compared to the forecast. The weather was generally cloudier than forecast for the morning and early afternoon but the forecast accurately predicted 100% cloud cover from mid-afternoon onwards. The error in the cloud cover forecast may have contributed to the variance in the load forecast in the early part of the day.

Figure 4(e) shows the actual wind speed in St. John's compared to the forecast. For most of the day the actual wind speed was lower than predicted so the error in the wind speed forecast would have led to lower than forecast load.

The discrepancy between actual and forecast load for March 5 was likely primarily a result of the error in the temperature forecast, combined with the unusual temperature trend during the day. By late morning, the forecast had improved and was within 2% of the actual. The hourly within-day updates are used by Energy Control Centre operators to manage spinning reserve.

2.5 March 11, 2015

On March 11, the forecast peak at 7:20 am, as reported to the Board, was 1540 MW; the actual reported peak was 1457 MW. The absolute difference was 83 MW, 5.7% of the actual. Figure 6 includes an hourly plot of the load forecast for March 11 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 6(a) shows the hourly distribution of the load forecast compared to the actual load. The actual load shape followed the forecast for much of the day, but both the morning and evening peaks were lower than forecast. The forecast predicted a 8:00 am peak of 1542 MW. The actual hourly peak was at 8:00 am, but was 1449 MW (Nostradamus only inputs data once per hour).

Figure 6(b) shows the hourly distribution of the utility load forecast only, i.e., the load forecast with the industrial component removed. The utility load forecast was only marginally more accurate than the total forecast.

Figure 6(c) shows the actual temperature in St. John's compared to the forecast. Although Nostradamus uses weather data at four sites, the weather in St. John's tends to have the largest effect because of the concentration of population in St. John's. The actual temperature was higher than forecast for the early hours of the morning and then briefly below forecast for the hour before the peak. The actual temperature was then close to forecast for most of the rest of the day. The error in the temperature forecast may have contributed somewhat to the error in the load forecast at the time of the peak.

Figure 6(d) shows the actual cloud cover in St. John's compared to the forecast. The cloud cover forecast was poor for most of the day, but was actually quite close for the time of the peak, so the error in the cloud cover forecast did not contribute to the variance in the load forecast.

Figure 6(e) shows the actual wind speed in St. John's compared to the forecast. The wind forecast was also quite poor and it was less windy than forecast for most of the day. The overestimate of the wind speed likely contributed to the overestimate of the load.

The discrepancy between actual and forecast load for March 11 was likely a result of multiple factors, including errors in the temperature and wind forecasts and non-uniform customer behaviour which results in unpredictability in the load.

Figure 6 Accuracy Analysis - March 11, 2015