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March 17, 2015

The Board of Commissioners of Public Utilities
Prince Charles Building
120 Torbay Road, P.O. Box 21040
St. John's, Newfoundland & Labrador
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: February 2015.*

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

Yours truly,

NEWFOUNDLAND AND LABRADOR HYDRO

Geoffrey P. Young
Senior Legal Counsel

GPY/jc

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: February 2015

Newfoundland and Labrador Hydro

March 13, 2015

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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 to provide the weather parameters in the form of hourly weather forecasts for a seven-day period. At the same time as the weather forecast data is provided, AMEC also provides observed data at the same locations for the previous 24 hours (calendar day). 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 uses the following weather parameters: 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, 2012 to October 31, 2014 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 Load Forecasting Improvements

Hydro implemented the following changes to the load forecasting process in 2014:

- Additional training for staff;
- Updating to the most recent Nostradamus software version;
- 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.

The changes to the Nostradamus model have eliminated the erratic load shapes that were present in the forecasts at loads in excess of 1600 MW in January 2014 and improved the reliability of the peak forecast. In addition, improved model performance has allowed an increase in forecast update frequency to hourly throughout the day; previously the forecast was updated five times per day.

In mid-February, Hydro revised the procedures for Nostradamus to run the forecast for 'tomorrow' four times a day, with updates based on the current day's actual load pattern. Previously the 'tomorrow' forecast was run only once a day, and used the 'yesterday's' actual loads. This change has no effect on the values reported daily to the Board (which use the 'today' forecast), but should provide Energy Control Centre operators with improved information for planning the next day's generation.

In late-February Hydro started receiving a second daily weather forecast and an update of observed data at approximately 12:45 PM each day. To date this information is being used only on the Development environment. When testing is complete, likely by the end of March, the Production environment will be updated to receive the second forecast.

Additional improvements to the forecasting process are planned for 2015, as follows:

- A further update to the software once it is released by the vendor; and
- Monthly accuracy reporting on the weather forecasts from AMEC, which will improve the understanding of any Nostradamus forecast variance.

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 and it is anticipated that planned revisions will further improve the accuracy.

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. FEBRUARY 2015 FORECAST ACCURACY

2.1 February Adjustments

On February 5, an error in plant load data coming from the Bay d'Espoir generating station led to an incorrect calculated 'actual' load value of 950 MW at 2 pm. In the Nostradamus databases, this value was replaced with a value of 1291 MW which was the average of the values at 1 pm and 3 pm. This data error had no effect on management of the system.

2.2 Description of Forecast

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 February 2015. The data are also presented in Figure 1. The actual peaks, as reported to the Board, varied from 1220 MW on February 1 and 1661 MW on February 9.

The available capacity during the month was between 1845 MW on February 27 and 1945 MW on February 24. Reserves were sufficient throughout the period.

Table 1 February 2015 Load Forecasting Data

Date	Forecast Peak, MW	Actual Peak, MW	Available Island Supply, MW	Forecast Reserve, MW
1-Feb-15	1225	1220	1910	780
2-Feb-15	1480	1587	1930	545
3-Feb-15	1495	1475	1895	495
4-Feb-15	1585	1552	1895	410
5-Feb-15	1625	1608	1895	370
6-Feb-15	1390	1389	1900	605
7-Feb-15	1465	1511	1905	535
8-Feb-15	1490	1537	1915	520
9-Feb-15	1630	1661	1870	340
10-Feb-15	1640	1652	1920	380
11-Feb-15	1615	1499	1910	395
12-Feb-15	1605	1642	1940	435
13-Feb-15	1500	1504	1890	490
14-Feb-15	1470	1452	1925	550
15-Feb-15	1455	1435	1900	540
16-Feb-15	1460	1449	1905	540
17-Feb-15	1510	1531	1935	525
18-Feb-15	1520	1502	1885	465
19-Feb-15	1405	1413	1900	590
20-Feb-15	1370	1285	1925	650
21-Feb-15	1470	1490	1935	560
22-Feb-15	1445	1436	1905	555
23-Feb-15	1330	1312	1915	680
24-Feb-15	1510	1607	1945	535
25-Feb-15	1655	1640	1890	335
26-Feb-15	1420	1416	1940	615
27-Feb-15	1440	1432	1845	500
28-Feb-15	1550	1528	1865	415

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).

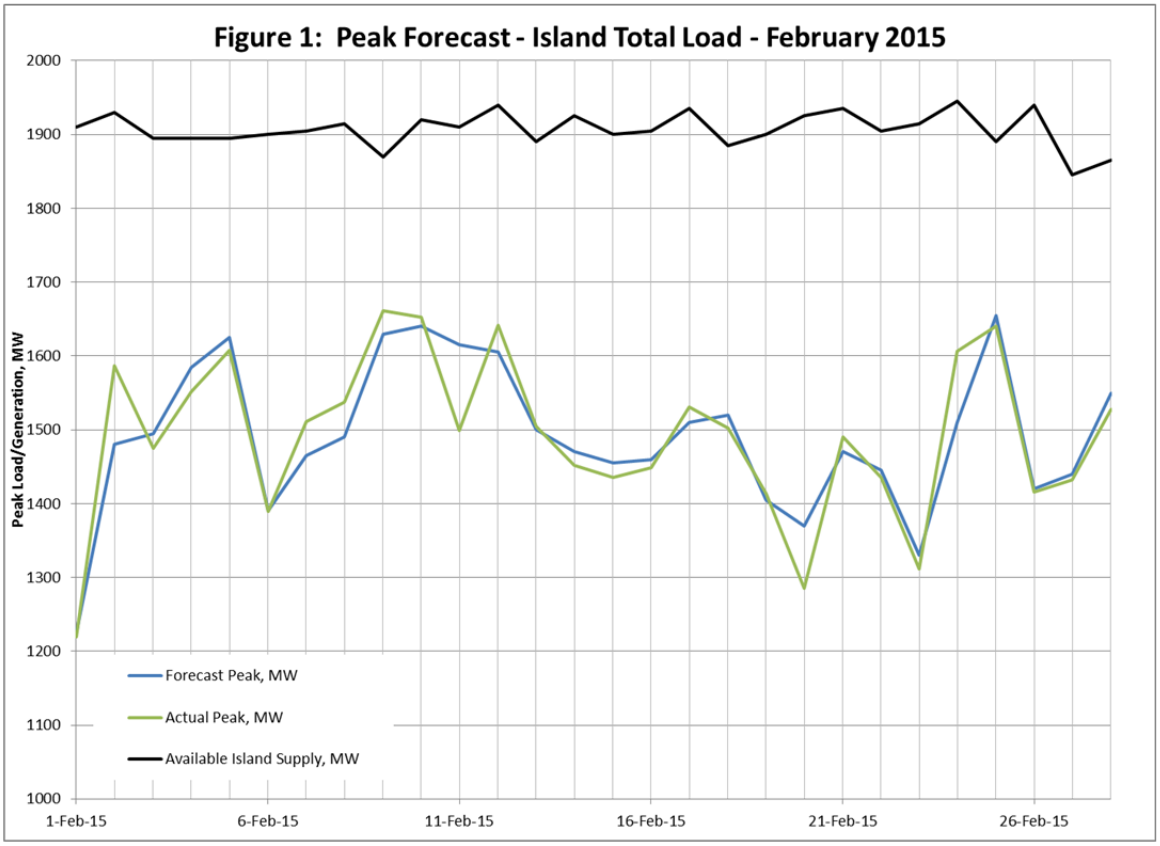


Figure 1: Peak Forecast - Island Total Load - February 2015

Table 2 presents error statistics for the peak forecasts during the month of February 2015. 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.

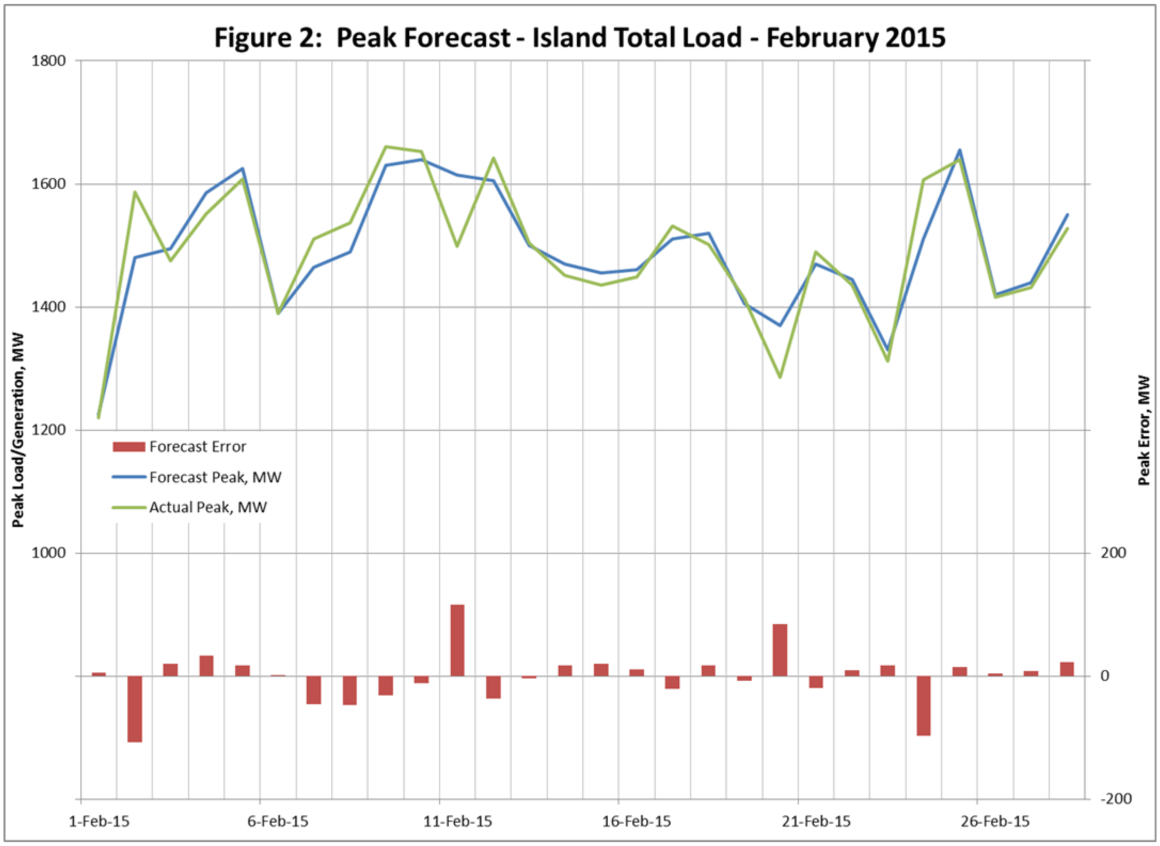
Through the month of February the forecast peak was in a range between 7% below the actual peak and 8% above the actual peak. On the best day the forecast peak was essentially the same as the actual peak; on the worst day it was 116 MW too high. On average, the forecast peak was 30 MW different than the actual peak, or 2.0%.

In the review of forecast accuracy statistics for February 2015 in Table 2, Hydro offers further detail on the difference found between forecast and actual peak for February 2, 11, 20 and 24. On February 2 and February 24 the forecast underestimated the peak by 6 to 7%. On February 11 and 20 the forecast overestimated the peak by 7 to 8%.

Table 2 February 2015 Analysis of Forecast Error

Date	Actual Peak, MW	Forecast Peak, MW	Error, MW	Absolute Error, MW	Percent Error	Absolute Percent Error	Actual/ Forecast
1-Feb-15	1220	1225	5	5	0.4%	0.4%	0.4%
2-Feb-15	1587	1480	-107	107	-6.7%	6.7%	-7.2%
3-Feb-15	1475	1495	20	20	1.4%	1.4%	1.3%
4-Feb-15	1552	1585	33	33	2.1%	2.1%	2.1%
5-Feb-15	1608	1625	17	17	1.1%	1.1%	1.0%
6-Feb-15	1389	1390	1	1	0.1%	0.1%	0.1%
7-Feb-15	1511	1465	-46	46	-3.0%	3.0%	-3.1%
8-Feb-15	1537	1490	-47	47	-3.1%	3.1%	-3.2%
9-Feb-15	1661	1630	-31	31	-1.9%	1.9%	-1.9%
10-Feb-15	1652	1640	-12	12	-0.7%	0.7%	-0.7%
11-Feb-15	1499	1615	116	116	7.7%	7.7%	7.2%
12-Feb-15	1642	1605	-37	37	-2.3%	2.3%	-2.3%
13-Feb-15	1504	1500	-4	4	-0.3%	0.3%	-0.3%
14-Feb-15	1452	1470	18	18	1.2%	1.2%	1.2%
15-Feb-15	1435	1455	20	20	1.4%	1.4%	1.4%
16-Feb-15	1449	1460	11	11	0.8%	0.8%	0.8%
17-Feb-15	1531	1510	-21	21	-1.4%	1.4%	-1.4%
18-Feb-15	1502	1520	18	18	1.2%	1.2%	1.2%
19-Feb-15	1413	1405	-8	8	-0.6%	0.6%	-0.6%
20-Feb-15	1285	1370	85	85	6.6%	6.6%	6.2%
21-Feb-15	1490	1470	-20	20	-1.3%	1.3%	-1.4%
22-Feb-15	1436	1445	9	9	0.6%	0.6%	0.6%
23-Feb-15	1312	1330	18	18	1.4%	1.4%	1.4%
24-Feb-15	1607	1510	-97	97	-6.0%	6.0%	-6.4%
25-Feb-15	1640	1655	15	15	0.9%	0.9%	0.9%
26-Feb-15	1416	1420	4	4	0.3%	0.3%	0.3%
27-Feb-15	1432	1440	8	8	0.6%	0.6%	0.6%
28-Feb-15	1528	1550	22	22	1.4%	1.4%	1.4%
Minimum	1220	1225	-107	1	-6.7%	0.1%	-7.2%
Average	1492	1491	0	30	0.1%	2.0%	0.0%
Maximum	1661	1655	116	116	7.7%	7.7%	7.2%

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.



2.3 February 2, 2015

On February 2, the peak of the 7:20 am forecast was 1480 MW; the actual peak was 1587 MW. The absolute difference was 107 MW, 6.7% of the actual. Figure 3 includes an hourly plot of the load forecast for February 2 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 Accuracy Analysis - February 2, 2015

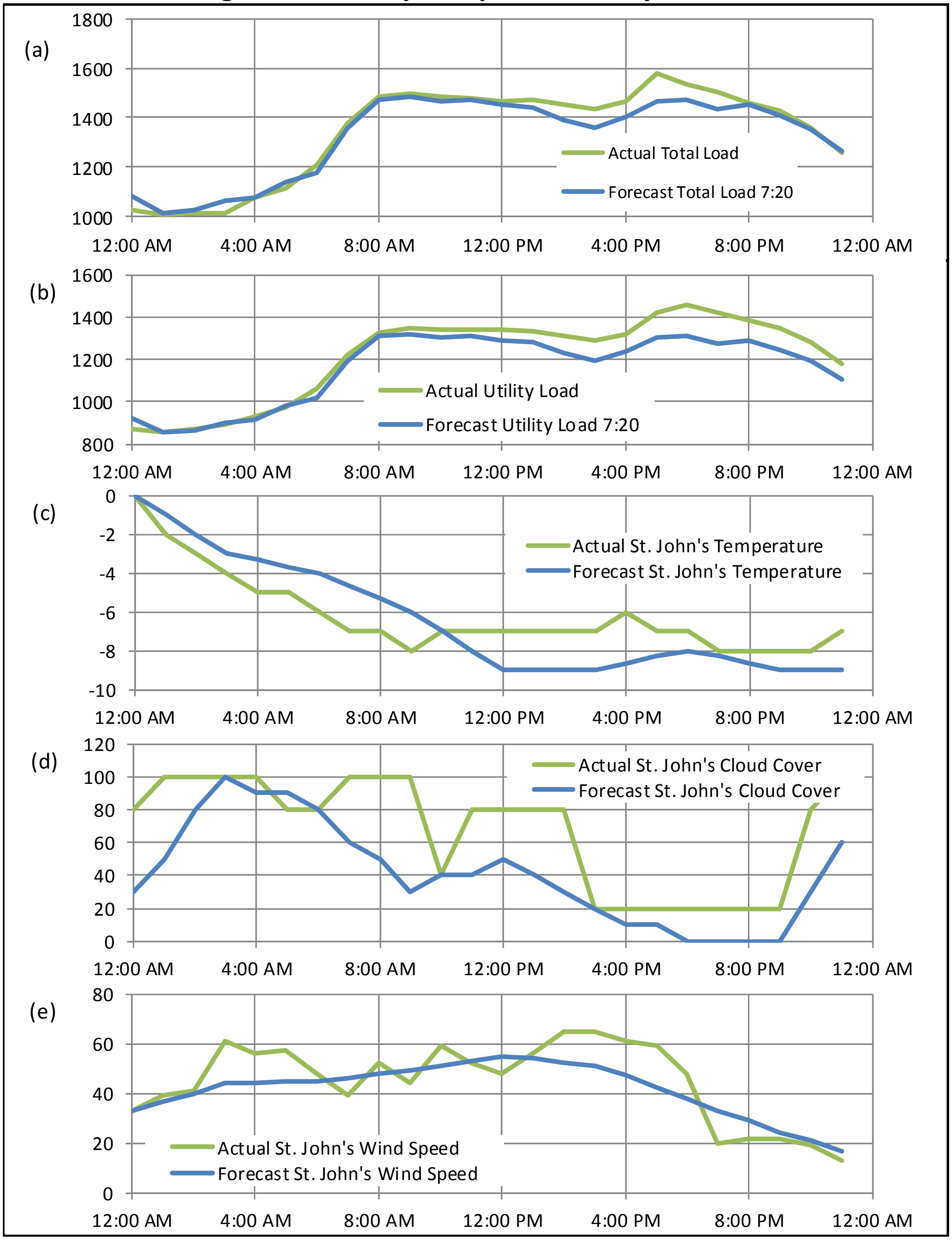


Figure 3(a) shows the hourly distribution of the load forecast compared to the actual load. The forecast predicted a morning peak of 1480 MW. The actual peak was 1587 MW at approximately 5:15 pm (the plot shows a peak of 1576 MW as it was created with data from Nostradamus which is input on the hour only).

Figure 3(b) shows the hourly distribution of the utility load forecast only, i.e., the load forecast with the industrial component removed. The difference between the forecast and actual utility loads is greater than the difference between the forecast and actual total load, so a discrepancy in the industrial forecast actually creates an apparent improvement in the total forecast.

Figure 3(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 customers in St. John's. The temperature was forecast to be lower during the afternoon and evening than it actually was, so the error in the temperature forecast did not contribute to the error in the peak load forecast.

Figure 3(d) shows the actual cloud cover in St. John's compared to the forecast. For most of the day, the weather was cloudier than forecast. The forecast predicted a clearing trend from 100% cloud cover at 3:00 am to clear skies at 6:00 pm. During the afternoon peak, the actual cloud cover was approximately 20%. The error in the cloud cover forecast was relatively minor and therefore did not likely contribute to the under forecast of the peak load.

Figure 3(e) shows the actual wind speed in St. John's compared to the forecast. At the time of the peak, the wind speed was significantly higher than predicted so the error in the wind speed forecast may have contributed to the under forecast of the peak. However, shortly after the peak, the wind speed dropped to below forecast, but the load forecast continued to underestimate the load.

It is difficult to ascertain with certainty why Nostradamus underestimated the load for the afternoon and evening of February 2. Errors in the weather forecast likely contributed somewhat to the underestimate but other factors, not modelled by Nostradamus, may also have increased the load that day, for instance wind direction, precipitation, or human behaviour. System Operations has noted that this same pattern of forecast discrepancy has occurred previously on days when temperature has plateaued or dropped during the day, rather than following a more typical warming and cooling pattern. System Operations will continue to investigate these types of discrepancies.

The Nostradamus model runs every hour to use actual loads experienced that day to improve the estimate for the rest of the day. By the mid-day update, the forecast peak for February 2 was 1591 MW, 15 MW, or 1% above actual. These within day updates are used by Energy Control Centre operators to manage spinning reserve.

2.4 February 11, 2015

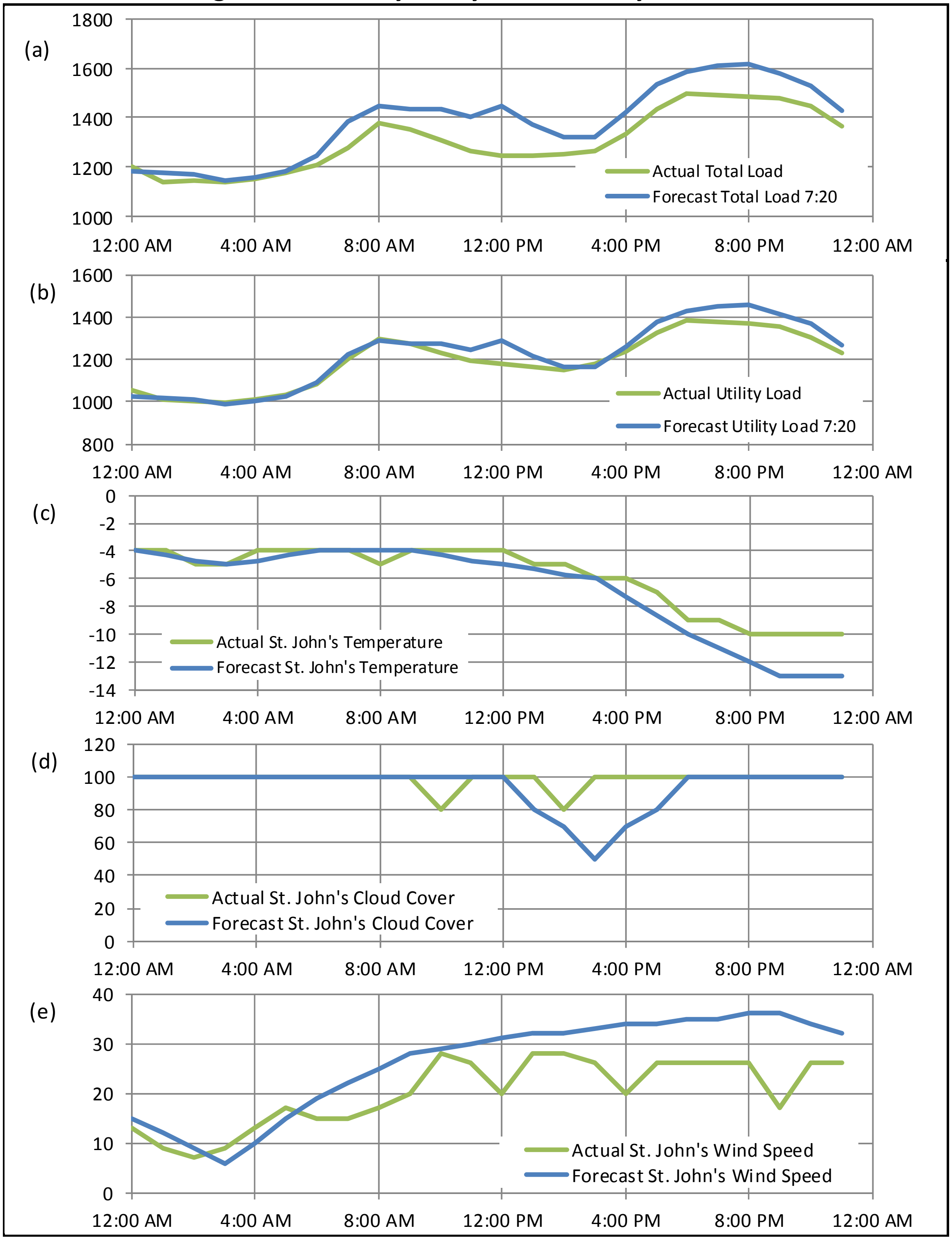
On February 11, the forecast peak created at 7:20 am was 1615 MW; the actual peak was 1499 MW. The absolute difference was 116 MW, 7.7% of the actual. Figure 4 includes an hourly plot of the load forecast for February 11 as well as several charts which examine components of the load forecast to assist in determining the sources of the differences between actual and forecast loads.

Figure 4(a) shows the hourly distribution of the load forecast compared to the actual load. The forecast predicted an afternoon peak of 1615 MW. The actual peak was 1499 MW at 6 pm.

Figure 4(b) shows the hourly distribution of the utility load forecast only, i.e., the load forecast with the industrial component removed. The difference between the forecast and actual utility loads is considerably less than the difference between the forecast and actual total load indicating that much of the discrepancy was in the industrial forecast. The default load forecast for Kruger is 108 MW but the load was less than on February 11; it varied between 20 MW and 75 MW for most of the day. Energy Control Centre Operators were aware of the loading reduction and responded according. This discrepancy in the industrial forecast explains most of the error in the total load forecast.

Figures 4(c) through 4(e) show elements of the weather forecast for St. John’s. Actual temperature and cloud cover at the time of the peak were similar to forecast, and the actual wind speed was lower than forecast, so errors in the weather forecast did not contribute to the error in the peak load forecast.

Figure 4 Accuracy Analysis - February 11, 2015



2.5 February 20, 2015

On February 20, the peak of the 7:20 am forecast was 1370 MW; the actual peak was 1285 MW. The absolute difference was 85 MW, 6.6% of the actual. Figure 5 includes an hourly plot of the load forecast for February 20 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. The forecast for the morning peak was accurate, with a difference of only 3 MW, however, the forecast predicted that the daily peak would occur in the afternoon and be 1370 MW. The peak load in the afternoon was lower than in the morning, only 1238 MW.

Figure 5(b) shows the hourly distribution of the utility load forecast only, i.e., the load forecast with the industrial component removed. The difference between the forecast and actual utility loads is marginally less than the difference between the forecast and actual total load, so a discrepancy in the industrial forecast contributes somewhat to the forecast error.

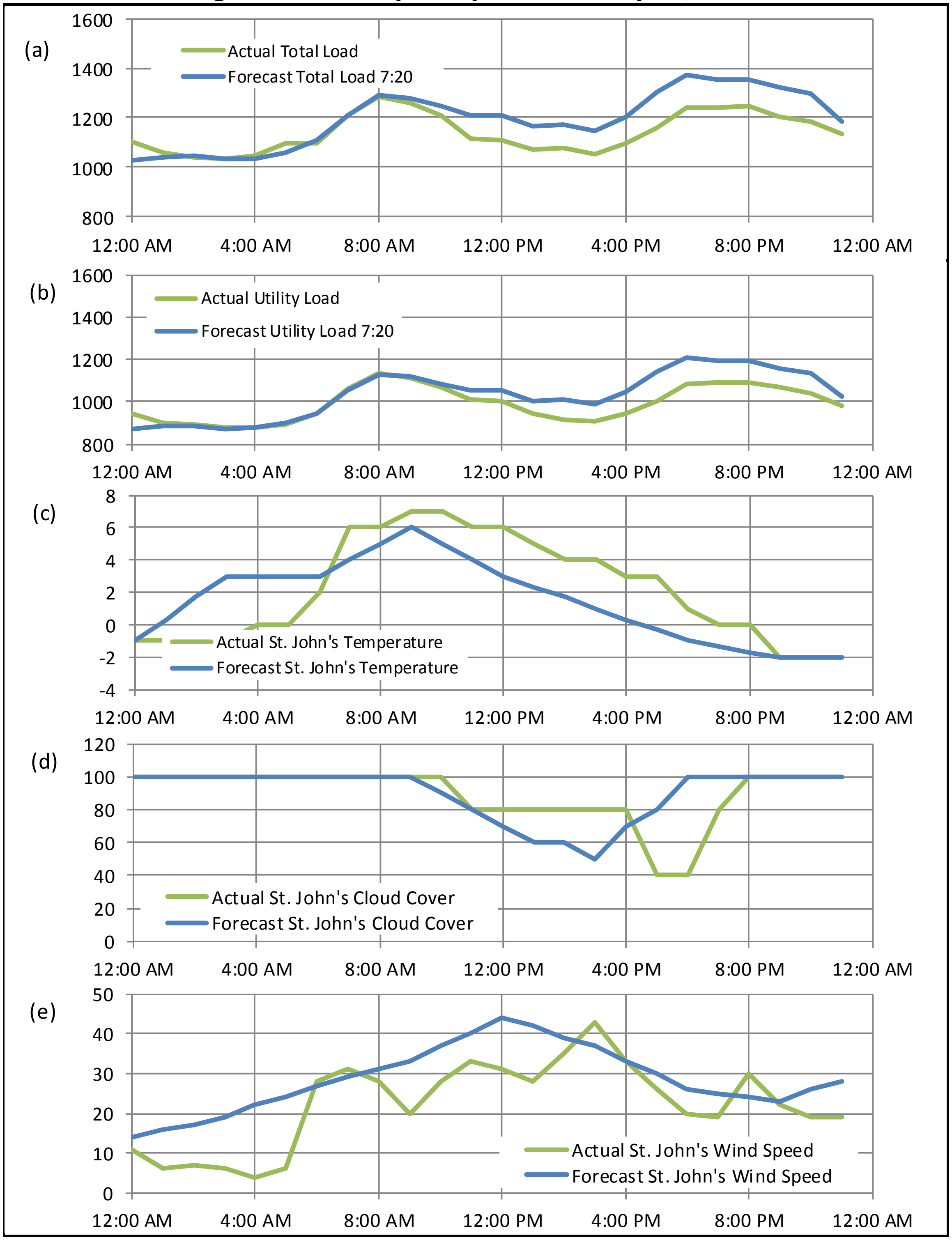
Figure 5(c) shows the actual temperature in St. John's compared to the forecast. Although Nostradamus uses weather data at four sites, the weather in St. John's tends to have the largest effect because of the concentration of customers in St. John's. At the time of the morning peak, the temperature forecast was within one degree of actual. For most of the rest of the day, however, the temperature was forecast to be two to four degrees lower than it actually was which likely explains why the model predicted a higher afternoon peak.

Figure 5(d) shows the actual cloud cover in St. John's compared to the forecast. At the time of the peak the forecast and actual cloud cover were both 100%. For parts of the day it was cloudier than forecast and for parts of the day it was less cloudy than forecast so the error in the cloud cover forecast did not likely contribute significantly to the error in the load forecast.

Figure 5(e) shows the actual wind speed in St. John's compared to the forecast. For most of the day the wind forecast was fairly accurate, with the actual wind speed equal to or lower than the forecast so the error in the wind speed forecast did not contribute to the error in the load forecast.

The Nostradamus model runs every hour to use actual loads experienced that day to improve the estimate for the rest of the day. By early afternoon, the load forecast was indicating that the afternoon peak would be lower than the morning peak. These within day updates are used by Energy Control Centre operators to manage spinning reserve.

Figure 5 Accuracy Analysis - February 20, 2015



2.6 February 24, 2015

On February 24, the forecast for the day was run later than usual, at 7:38 am rather than 7:20 am, due to an issue with the automatic data input process. The peak of the first forecast was 1510 MW; the actual peak was 1607 MW. The absolute difference was 97 MW, 6.0% of the actual. Figure 3 includes an hourly plot of the load forecast for February 24 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 morning portion of the forecast was quite accurate, but the afternoon peak was underestimated.

Figure 6(b) shows the hourly distribution of the utility load forecast only, i.e., the load forecast with the industrial component removed. The difference between the forecast and actual utility loads is similar to the between the forecast and actual total load, so there was little error in the industrial 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 customers in St. John's. For most of the day the temperature was marginally cooler than forecasts which may have contributed somewhat to the error in the load forecast. In addition, February 24 was another day when the temperature decreased during the day; it has been noted that Nostradamus sometimes performs poorly when this type of temperature trend occurs.

Figures 6(d) and (e) show the actual cloud cover and wind speed in St. John's compared to the forecast. Both forecasts were quite accurate and therefore did not contribute to the error in the load forecast.

The Nostradamus model runs every hour to use actual loads experienced that day to improve the estimate for the rest of the day. By mid-afternoon, the load forecast for the afternoon peak was within 1 % of actual. These within day updates are used by Energy Control Centre operators to manage spinning reserve.

Figure 6 Accuracy Analysis - February 24, 2015