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February 11, 2015

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

Newfoundland and Labrador Hydro

February 10, 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 with-in 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.

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;
- A move to twice daily weather forecasting and receipt of observed data which will improve forecasting of the afternoon peak and the following day; 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. JANUARY 2015 FORECAST ACCURACY

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 January 2015. The data are also presented in Figure 1.

2.1 January Adjustments

There was one day in early January when System Operations engineers decided it was necessary to make an adjustment to the Nostradamus forecast to account for the coincidence of low temperatures with the ongoing impact of the Christmas period on the domestic load. Using guidance from Hydro's System Planning group, System Operations added 34 MW to the forecast from 3:00 pm till 11:00 pm on January 3.

On January 6 and again on January 14, Newfoundland Power requested a short-term voltage reduction during the expected peak demand period in order to reduce the peak. Therefore, System Operations adjusted the Island utility load values input to Nostradamus upwards by 20 MW for two hourly readings, estimated from the observed decrease in the load when the voltage reduction was put in place.

- January 6, 2015 17:00 load increased from 1478 MW to 1498 MW
- January 6, 2015 18:00 load increased from 1476 MW to 1496 MW
- January 14, 2015 08:00 load increased from 1501 MW to 1521 MW
- January 14, 2015 09:00 load increased from 1465 MW to 1485 MW

A portion of the 20 MW adjustment, namely 10 MW, was added to the Avalon utility load for the same periods.

These adjustments were made to the Nostradamus data so that in the future, when January 2015 is used in training the forecasting model, Nostradamus will use a value that is not affected by the requested voltage reduction. The adjustments were not made to any other database, and were not made to the values reported in the daily Supply and Demand Status Reports.

The observed peaks during January 2015 were between 1290 MW on January 29 and 1660 MW on January 14. There were peaks above 1600 MW, which would be considered a high demand, on eight days: January 3, 4, 6, 8, 9, 12, 14 and 27. It was at loads in excess of 1600 MW in January 2014 that the Nostradamus model provided erratic results.

Table 1 January 2015 Load Forecasting Data

Date	Forecast Peak, MW	Actual Peak, MW	Available Island Supply, MW	Forecast Reserve, MW
1-Jan-15	1575	1537	1770	295
2-Jan-15	1475	1389	1875	495
3-Jan-15	1650	1639	1885	335
4-Jan-15	1575	1639	1860	385
5-Jan-15	1400	1374	1900	595
6-Jan-15	1525	1641	1900	475
7-Jan-15	1550	1579	1875	425
8-Jan-15	1550	1608	1875	425
9-Jan-15	1625	1636	1875	350
10-Jan-15	1495	1471	1730	330
11-Jan-15	1520	1566	1890	470
12-Jan-15	1600	1606	1865	365
13-Jan-15	1575	1589	1895	420
14-Jan-15	1660	1660	1860	300
15-Jan-15	1515	1501	1845	430
16-Jan-15	1405	1423	1865	555
17-Jan-15	1450	1428	1870	515
18-Jan-15	1460	1515	1875	510
19-Jan-15	1415	1434	1855	535
20-Jan-15	1365	1325	1905	635
21-Jan-15	1375	1416	1885	605
22-Jan-15	1425	1419	1860	530
23-Jan-15	1465	1460	1890	520
24-Jan-15	1460	1470	1855	490
25-Jan-15	1335	1362	1865	625
26-Jan-15	1470	1543	1905	530
27-Jan-15	1565	1640	1865	400
28-Jan-15	1340	1311	1900	655
29-Jan-15	1335	1290	1905	665
30-Jan-15	1390	1424	1930	635
31-Jan-15	1380	1369	1900	615

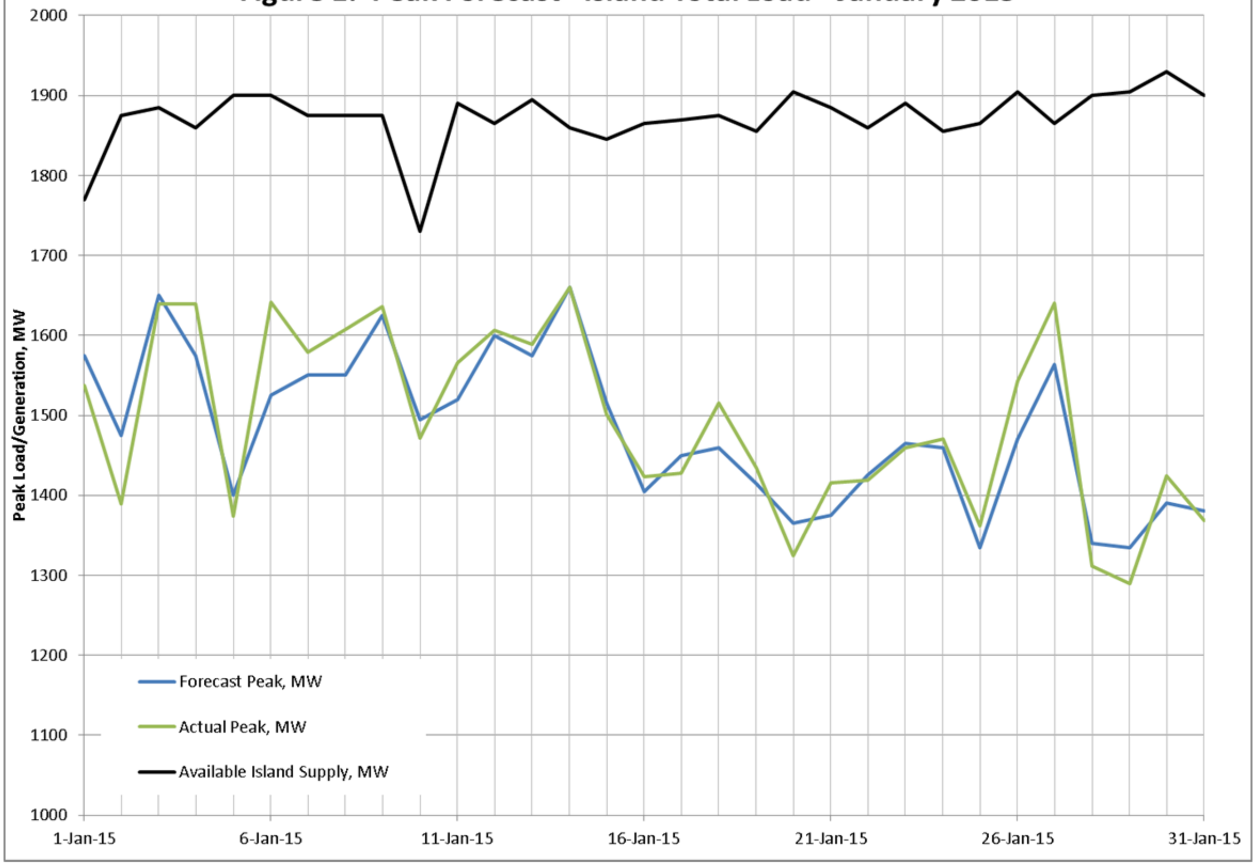
Notes:

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) - impact of voltage reduction)

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



The available capacity during the month was between 1730 MW on January 10 and 1930 MW on January 30. Reserves were sufficient throughout the period.

Table 2 presents error statistics for the peak forecasts during the month of January 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 January the forecast peak was in a range between 7% below the actual peak and 6% above the actual peak. On the best day the forecast peak was the same as the actual peak; on the worst day it was 116 MW too low. On average, the forecast peak was 34 MW different than the actual peak, or 2.3%.

Table 2 January 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-Jan-15	1537	1575	38	38	2.5%	2.5%	2.4%
2-Jan-15	1389	1475	86	86	6.2%	6.2%	5.8%
3-Jan-15	1639	1650	11	11	0.7%	0.7%	0.7%
4-Jan-15	1639	1575	-64	64	-3.9%	3.9%	-4.1%
5-Jan-15	1374	1400	26	26	1.9%	1.9%	1.9%
6-Jan-15	1641	1525	-116	116	-7.1%	7.1%	-7.6%
7-Jan-15	1579	1550	-29	29	-1.8%	1.8%	-1.9%
8-Jan-15	1608	1550	-58	58	-3.6%	3.6%	-3.7%
9-Jan-15	1636	1625	-11	11	-0.7%	0.7%	-0.7%
10-Jan-15	1471	1495	24	24	1.6%	1.6%	1.6%
11-Jan-15	1566	1520	-46	46	-2.9%	2.9%	-3.0%
12-Jan-15	1606	1600	-6	6	-0.4%	0.4%	-0.4%
13-Jan-15	1589	1575	-14	14	-0.9%	0.9%	-0.9%
14-Jan-15	1660	1660	0	0	0.0%	0.0%	0.0%
15-Jan-15	1501	1515	14	14	0.9%	0.9%	0.9%
16-Jan-15	1423	1405	-18	18	-1.3%	1.3%	-1.3%
17-Jan-15	1428	1450	22	22	1.5%	1.5%	1.5%
18-Jan-15	1515	1460	-55	55	-3.6%	3.6%	-3.8%
19-Jan-15	1434	1415	-19	19	-1.3%	1.3%	-1.3%
20-Jan-15	1325	1365	40	40	3.0%	3.0%	2.9%
21-Jan-15	1416	1375	-41	41	-2.9%	2.9%	-3.0%
22-Jan-15	1419	1425	6	6	0.4%	0.4%	0.4%
23-Jan-15	1460	1465	5	5	0.3%	0.3%	0.3%
24-Jan-15	1470	1460	-10	10	-0.7%	0.7%	-0.7%
25-Jan-15	1362	1335	-27	27	-2.0%	2.0%	-2.0%
26-Jan-15	1543	1470	-73	73	-4.7%	4.7%	-5.0%
27-Jan-15	1640	1565	-75	75	-4.6%	4.6%	-4.8%
28-Jan-15	1311	1340	29	29	2.2%	2.2%	2.2%
29-Jan-15	1290	1335	45	45	3.5%	3.5%	3.4%
30-Jan-15	1424	1390	-34	34	-2.4%	2.4%	-2.4%
31-Jan-15	1369	1380	11	11	0.8%	0.8%	0.8%
Minimum	1290	1335	-116	0	-7.1%	0.0%	-7.6%
Average	1492	1481	-11	34	-0.6%	2.3%	-0.7%
Maximum	1660	1660	86	116	6.2%	7.1%	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.

In the review of forecast accuracy statistics for January 2015 in Table 2, Hydro offers further detail on the difference found between forecast and actual peak for January 6th, when the peak was underestimated by 116 MW, or 7.1%.

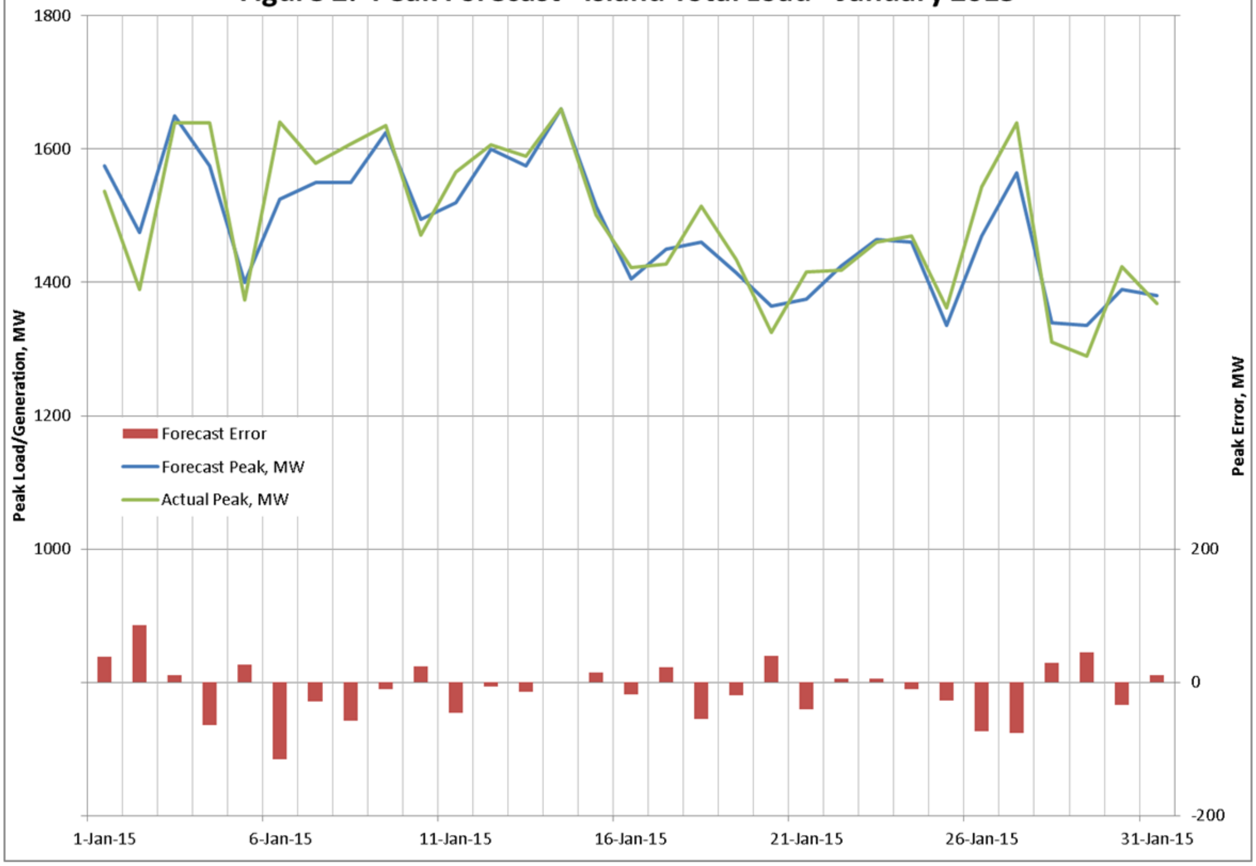


Figure 2: Peak Forecast - Island Total Load - January 2015

2.2 January 6, 2015

On January 6, the forecast peak created at 7:20 am was 1525 MW; the actual peak was 1641 MW. The absolute difference was 116 MW, 7.1% of the actual. Figure 3 includes an hourly plot of the load forecast for January 6 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 predicted an evening peak of 1525 MW. The actual peak was 1641 MW at approximately 5:15 pm (the plot shows a peak of 1627 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 similar to that of the total load, so a discrepancy in the industrial forecast does not explain the variance in the peak.

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 approximately one degree 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 gradual clearing from 100% cloud cover at 6 am to clear skies at 9:00 pm. During the afternoon peak, the actual cloud cover was approximately 80%. The error in the cloud cover forecast likely contributed somewhat to the under forecast of the peak load.

Figure 3(e) shows the actual wind speed in St. John's compared to the forecast. For most of the day the actual wind speed was slightly higher than predicted so the error in the wind speed forecast may have contributed somewhat to the under forecast of the peak.

It is difficult to ascertain why Nostradamus underestimated the load for most of January 6. 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. It may be that Nostradamus's model is not representative on those types of days. 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 January 6 was 1576 MW, 65 MW, or only 4% below actual. These with-in day updates are used by Energy Control Centre operators to manage spinning reserve.

Figure 3 Accuracy Analysis - January 6, 2015