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May 12, 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: April 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: April 2016

Newfoundland and Labrador Hydro

May 12, 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 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 APRIL 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 April 2016. The data are also presented in Figure 1. The actual peaks, as reported to the Board, varied from 968 MW on April 2 to 1438 MW on April 4.

The available capacity during the month was between 1495 MW on April 30 and 1915 MW on April 3. Reserves were sufficient throughout the period.

Table 2 presents error statistics for the peak forecasts during the month of April 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 April the forecast peak was in a range between 4.4% below the actual peak and 10.6% 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 109 MW too high. On average, the forecast peak was 33 MW different than the actual peak, or 2.8%.

The overestimate of the load on some days in April was related to the CBPP portion of the industrial load forecast. The average hourly load at CBPP in April was 94 MW, 11 MW below forecast. On the lowest day, April 23, the average load was 64 MW, 43 MW below forecast. Figure 3 shows the CBPP load forecast, the actual load, and the discrepancy. Hydro's Energy Control Centre has a real time indication of the CBPP load and therefore operators were 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. Five days were initially of concern because of overestimates. With the industrial component of the forecast removed, four of those five days now show an underestimate in the order of 50 MW. This report will further investigate the error in the day of the highest absolute error, April 26.

Table 1 April 2016 Load Forecasting Data

Date	Forecast Peak, MW	Actual Peak, MW	Available Island Supply, MW	Forecast Reserve, MW
1-Apr-16	1175	1153	1855	680
2-Apr-16	985	968	1880	895
3-Apr-16	1025	1050	1915	890
4-Apr-16	1400	1438	1725	325
5-Apr-16	1445	1437	1720	275
6-Apr-16	1450	1434	1735	285
7-Apr-16	1455	1430	1735	280
8-Apr-16	1260	1213	1730	470
9-Apr-16	1040	1071	1735	695
10-Apr-16	1050	1098	1595	545
11-Apr-16	1270	1228	1755	485
12-Apr-16	1280	1250	1595	315
13-Apr-16	1145	1144	1595	450
14-Apr-16	1100	1073	1655	555
15-Apr-16	1115	1090	1720	605
16-Apr-16	1105	1106	1570	465
17-Apr-16	1100	1116	1565	465
18-Apr-16	1195	1172	1585	390
19-Apr-16	1300	1269	1570	270
20-Apr-16	1345	1354	1665	320
21-Apr-16	1280	1205	1655	375
22-Apr-16	1225	1182	1660	435
23-Apr-16	1140	1031	1640	500
24-Apr-16	1045	988	1645	600
25-Apr-16	1150	1108	1590	440
26-Apr-16	1260	1205	1570	310
27-Apr-16	1265	1261	1580	315
28-Apr-16	1225	1169	1550	325
29-Apr-16	1190	1165	1590	400
30-Apr-16	1105	1081	1495	390
Minimum	985	968	1495	270
Average	1204	1183	1663	458
Maximum	1455	1438	1915	895

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).

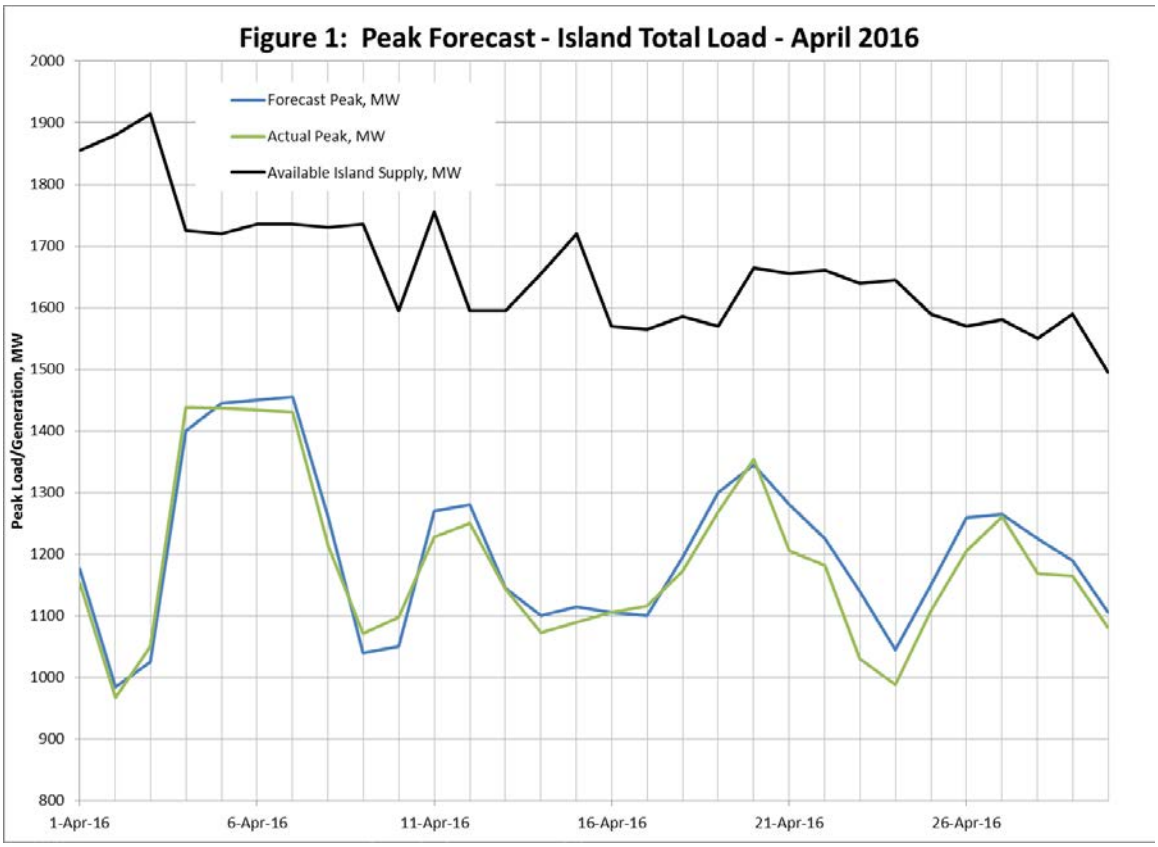
Figure 1: Peak Forecast - Island Total Load - April 2016
Forecast Peak, MW
Actual Peak, MW
Available Island Supply, MW
Peak Load/Generation, MW
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
1-Apr-16
6-Apr-16
11-Apr-16
16-Apr-16
21-Apr-16
26-Apr-16

Table 2 April 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-Apr-16	1153	1175	22	22	1.9%	1.9%	1.9%
2-Apr-16	968	985	17	17	1.8%	1.8%	1.7%
3-Apr-16	1050	1025	-25	25	-2.4%	2.4%	-2.4%
4-Apr-16	1438	1400	-38	38	-2.6%	2.6%	-2.7%
5-Apr-16	1437	1445	8	8	0.6%	0.6%	0.6%
6-Apr-16	1434	1450	16	16	1.1%	1.1%	1.1%
7-Apr-16	1430	1455	25	25	1.7%	1.7%	1.7%
8-Apr-16	1213	1260	47	47	3.9%	3.9%	3.7%
9-Apr-16	1071	1040	-31	31	-2.9%	2.9%	-3.0%
10-Apr-16	1098	1050	-48	48	-4.4%	4.4%	-4.6%
11-Apr-16	1228	1270	42	42	3.4%	3.4%	3.3%
12-Apr-16	1250	1280	30	30	2.4%	2.4%	2.3%
13-Apr-16	1144	1145	1	1	0.1%	0.1%	0.1%
14-Apr-16	1073	1100	27	27	2.5%	2.5%	2.5%
15-Apr-16	1090	1115	25	25	2.3%	2.3%	2.2%
16-Apr-16	1106	1105	-1	1	-0.1%	0.1%	-0.1%
17-Apr-16	1116	1100	-16	16	-1.4%	1.4%	-1.5%
18-Apr-16	1172	1195	23	23	2.0%	2.0%	1.9%
19-Apr-16	1269	1300	31	31	2.4%	2.4%	2.4%
20-Apr-16	1354	1345	-9	9	-0.7%	0.7%	-0.7%
21-Apr-16	1205	1280	75	75	6.2%	6.2%	5.9%
22-Apr-16	1182	1225	43	43	3.6%	3.6%	3.5%
23-Apr-16	1031	1140	109	109	10.6%	10.6%	9.6%
24-Apr-16	988	1045	57	57	5.8%	5.8%	5.5%
25-Apr-16	1108	1150	42	42	3.8%	3.8%	3.7%
26-Apr-16	1205	1260	55	55	4.6%	4.6%	4.4%
27-Apr-16	1261	1265	4	4	0.3%	0.3%	0.3%
28-Apr-16	1169	1225	56	56	4.8%	4.8%	4.6%
29-Apr-16	1165	1190	25	25	2.1%	2.1%	2.1%
30-Apr-16	1081	1105	24	24	2.2%	2.2%	2.2%
Minimum	968	985	-48	1	-4.4%	0.1%	-4.6%
Average	1183	1204	21	32	1.9%	2.8%	1.7%
Maximum	1438	1455	109	109	10.6%	10.6%	9.6%

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 - April 2016

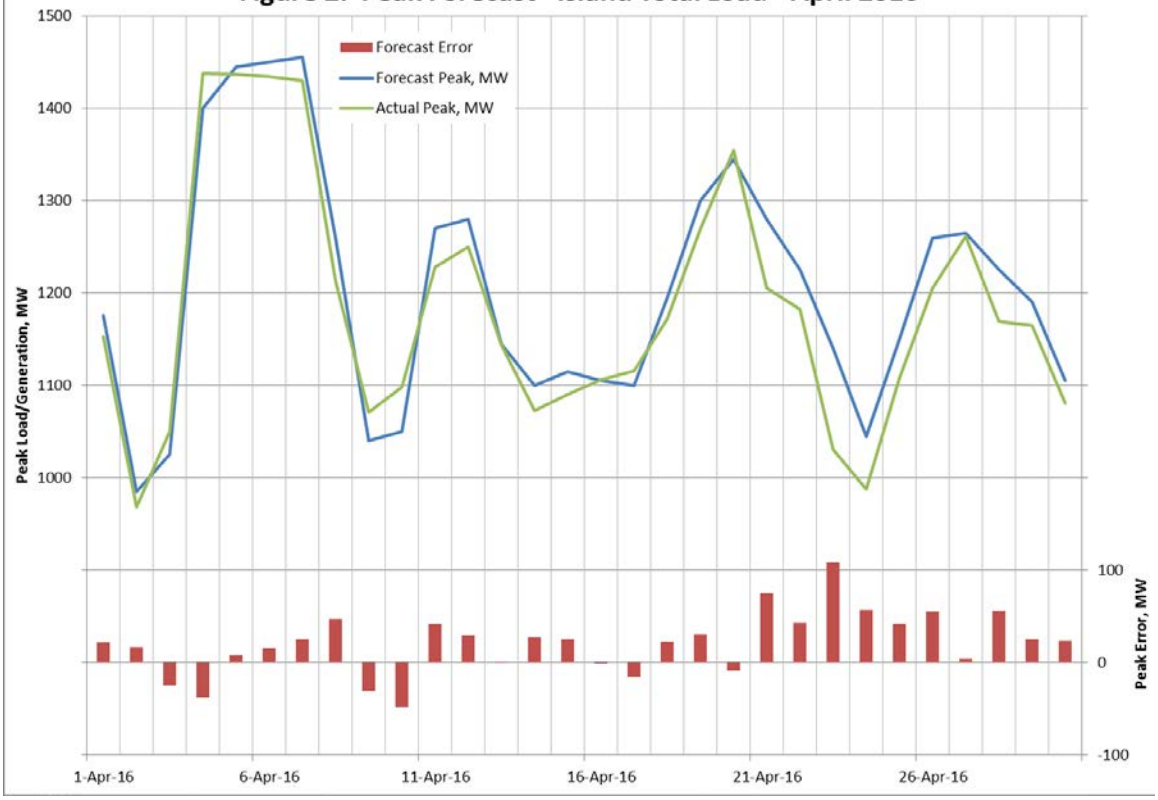

Figure 3: CBPP Load, April 2016, MW

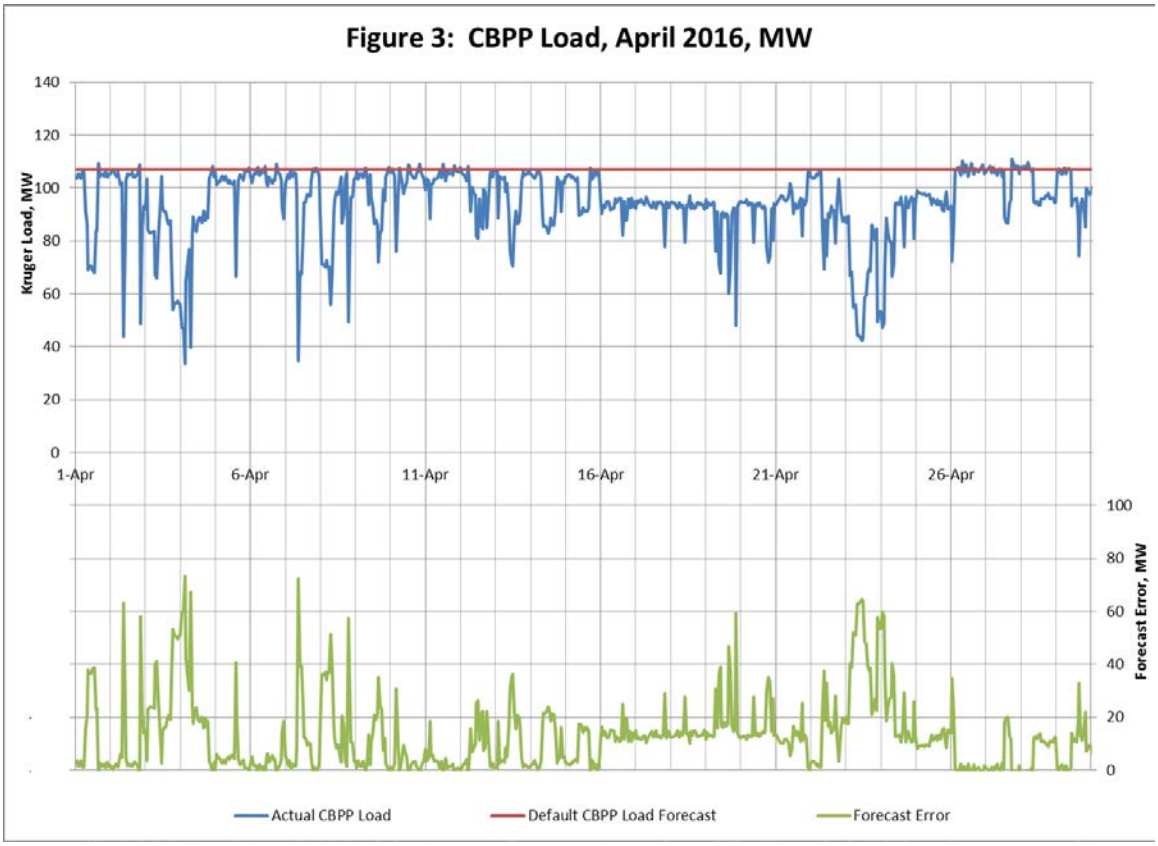

Table 3 April 2016 Analysis of Forecast Error

Date	Actual Peak, MW	Forecast Peak, MW	Error, MW	Absolute Error, MW	Percent Error	Absolute Percent Error	Actual/ Forecast
21-Apr-16	1110	1058	-52	52	-4.7%	4.7%	-4.9%
23-Apr-16	971	964	-7	7	-0.7%	0.7%	-0.7%
24-Apr-16	877	835	-42	42	-4.8%	4.8%	-5.0%
26-Apr-16	1094	1040	-54	54	-4.9%	4.9%	-5.2%
28-Apr-16	1056	1008	-48	48	-4.5%	4.5%	-4.8%

2.2 Data Adjustment

On April 12 and again on April 22 there were brief problems with the PI data base that resulted in one hour (on each day) of incorrect load data being imported into Nostradamus. These data points were corrected by replacement of the poor data with an average of the hour before and hour after. These erroneous data points led to incorrect forecast values for the following hours but this did not have any impact on system operation. The adjustment is made to the Nostradamus data so that in the future, when April 2016 data are used in training the forecasting model, Nostradamus will use a value that is not affected by the data error.

2.3 April 26, 2015

On April 26, the forecast peak at 7:20 am, as reported to the Board, was 1260 MW; the actual reported peak was 1205 MW. The absolute difference was 55 MW, 4.6% of the actual. Figure 4 includes an hourly plot of the load forecast for April 26 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 the morning (and daily) peak and underestimated the afternoon peak, but understated the load for the period in between peaks. The forecast accurately predicted the time of the peak, 8:00 am, 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 CBPP load was close to its forecast on April 26 and the error in the utility forecast is similar to the error in the total forecast.

Figure 4(c) through 4(e) show the actual temperature, cloud cover and wind speed compared to forecast. The weather forecast was fairly accurate for most of the day; in the early morning hours the actual temperature was a little higher and the average wind speed was a little lower than forecast. At 8:00 am the sky was clearer than forecast. All of these factors would have contributed to the overestimate of the load forecast. With the peak happening so early in the day, Nostradamus did not have much time to adjust the forecast based on the day's actual load.

Figure 4 Accuracy Analysis - April 26, 2016