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September 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: August 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/cp

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: August 2016

Newfoundland and Labrador Hydro

September 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 and Deer Lake. Data from August 1, 2013 to June 30, 2016 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 AUGUST 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 August 2016. The data are also presented in Figure 1. The actual peaks, as reported to the Board, varied from 687 MW on August 13 to 817 MW on August 30.

The available capacity during the month was between 1135 MW on August 25 and 1440 MW on August 28. Reserves were sufficient throughout the period.

Table 2 presents error statistics for the peak forecasts during the month of August 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 August the forecast peak was in a range between 0.7% below the actual peak and 9.5% 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 66 MW too high. On average, the forecast peak was 23 MW different than the actual peak, or 3.1%.

Figure 2 shows that there was a consistent overestimation of the total island load through August. A review of the CBPP load shows that it was below the forecasted 107 MW for much of the month. The average load was 90 MW, 17MW below the forecast of 107 MW, but several times the load dipped below 50 MW. Since the total load forecast is a sum of both the utility and industrial load forecasts, an industrial customer using less than forecast energy is a common cause of an overestimate in the load forecast. Figure 3 reproduces Figure 2 but analyzes the utility load, rather than the

total load. The error is generally significantly less, and more random, than the error in the total forecast.

This report will further examine the forecasts for August 14 and August 30. In both cases the utility-only forecast was better than the total forecast because of the impact of the lower than forecast CBPP load, but the errors in the peak were still greater than 5%.

Table 1 Aug 2016 Load Forecasting Data

Date	Forecast Peak, MW	Actual Peak, MW	Available Island Supply, MW	Forecast Reserve, MW
1-Aug-16	740	740	1195	455
2-Aug-16	765	747	1210	445
3-Aug-16	755	734	1190	435
4-Aug-16	755	739	1180	425
5-Aug-16	765	750	1205	440
6-Aug-16	750	755	1170	420
7-Aug-16	760	733	1205	445
8-Aug-16	770	722	1205	435
9-Aug-16	755	745	1215	460
10-Aug-16	750	730	1175	425
11-Aug-16	760	745	1185	425
12-Aug-16	765	733	1385	620
13-Aug-16	720	687	1405	685
14-Aug-16	750	705	1395	645
15-Aug-16	745	740	1350	605
16-Aug-16	760	694	1365	605
17-Aug-16	765	719	1345	580
18-Aug-16	765	745	1235	470
19-Aug-16	765	745	1230	465
20-Aug-16	745	707	1240	495
21-Aug-16	730	698	1240	510
22-Aug-16	755	731	1240	485
23-Aug-16	760	758	1250	490
24-Aug-16	755	756	1210	455
25-Aug-16	760	737	1135	375
26-Aug-16	755	758	1275	520
27-Aug-16	750	738	1395	645
28-Aug-16	740	716	1440	700
29-Aug-16	775	776	1275	500
30-Aug-16	880	817	1380	500
31-Aug-16	795	780	1300	505
Minimum	720	687	1135	375
Average	760	738	1265	505
Maximum	880	817	1440	700

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

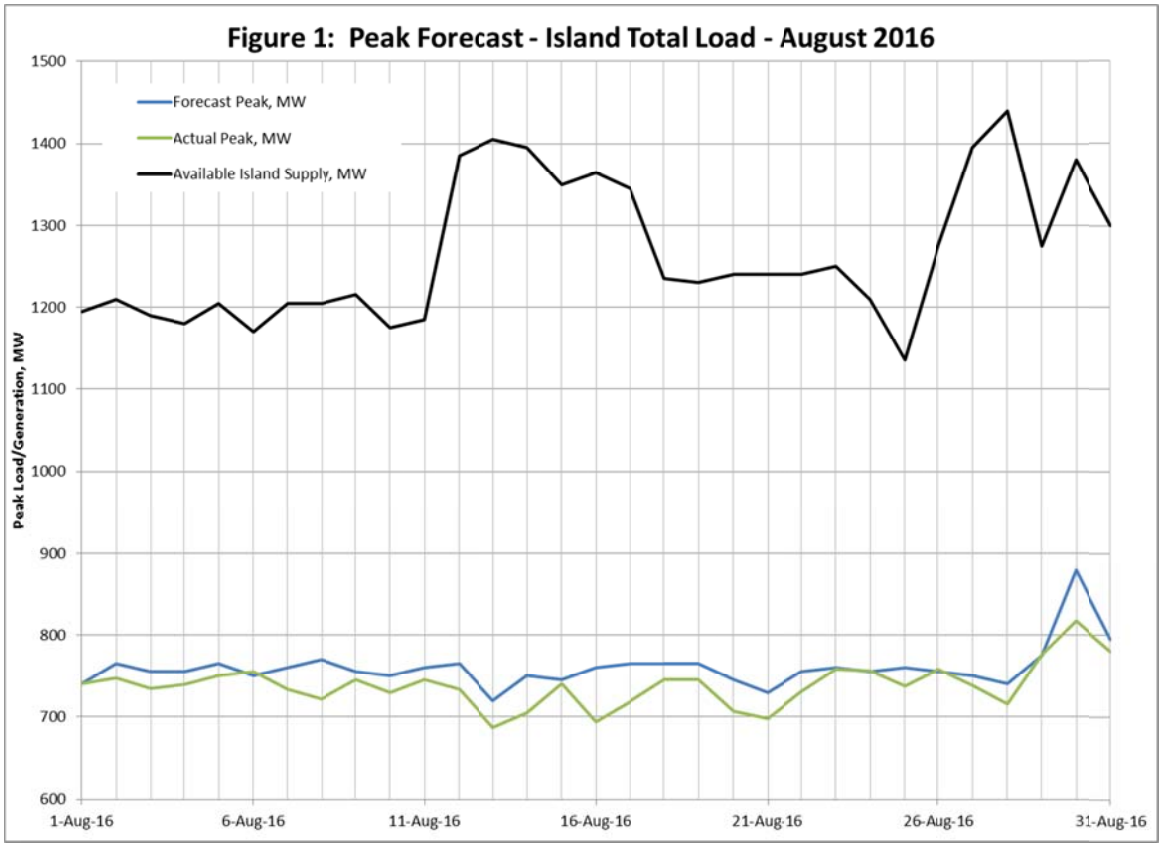


Figure 1: Peak Forecast - Island Total Load - August 2016
Forecast Peak, MW
Actual Peak, MW
Available Island Supply, MW
Peak Load/Generation, MW
1500
1400
1300
1200
1100
1000
900
800
700
600
1-Aug-16
6-Aug-16
11-Aug-16
16-Aug-16
21-Aug-16
26-Aug-16
31-Aug-16

Table 2 Aug 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-Aug-16	740	740	0	0	0.0%	0.0%	0.0%
2-Aug-16	747	765	18	18	2.4%	2.4%	2.4%
3-Aug-16	734	755	21	21	2.9%	2.9%	2.8%
4-Aug-16	739	755	16	16	2.2%	2.2%	2.1%
5-Aug-16	750	765	15	15	2.0%	2.0%	2.0%
6-Aug-16	755	750	-5	5	-0.7%	0.7%	-0.7%
7-Aug-16	733	760	27	27	3.7%	3.7%	3.6%
8-Aug-16	722	770	48	48	6.6%	6.6%	6.2%
9-Aug-16	745	755	10	10	1.3%	1.3%	1.3%
10-Aug-16	730	750	20	20	2.7%	2.7%	2.7%
11-Aug-16	745	760	15	15	2.0%	2.0%	2.0%
12-Aug-16	733	765	32	32	4.4%	4.4%	4.2%
13-Aug-16	687	720	33	33	4.8%	4.8%	4.6%
14-Aug-16	705	750	45	45	6.4%	6.4%	6.0%
15-Aug-16	740	745	5	5	0.7%	0.7%	0.7%
16-Aug-16	694	760	66	66	9.5%	9.5%	8.7%
17-Aug-16	719	765	46	46	6.4%	6.4%	6.0%
18-Aug-16	745	765	20	20	2.7%	2.7%	2.6%
19-Aug-16	745	765	20	20	2.7%	2.7%	2.6%
20-Aug-16	707	745	38	38	5.4%	5.4%	5.1%
21-Aug-16	698	730	32	32	4.6%	4.6%	4.4%
22-Aug-16	731	755	24	24	3.3%	3.3%	3.2%
23-Aug-16	758	760	2	2	0.3%	0.3%	0.3%
24-Aug-16	756	755	-1	1	-0.1%	0.1%	-0.1%
25-Aug-16	737	760	23	23	3.1%	3.1%	3.0%
26-Aug-16	758	755	-3	3	-0.4%	0.4%	-0.4%
27-Aug-16	738	750	12	12	1.6%	1.6%	1.6%
28-Aug-16	716	740	24	24	3.4%	3.4%	3.2%
29-Aug-16	776	775	-1	1	-0.1%	0.1%	-0.1%
30-Aug-16	817	880	63	63	7.7%	7.7%	7.2%
31-Aug-16	780	795	15	15	1.9%	1.9%	1.9%
Minimum	687	720	-5	0	-0.7%	0.0%	-0.7%
Average	738	760	22	23	3.0%	3.1%	2.9%
Maximum	817	880	66	66	9.5%	9.5%	8.7%

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.

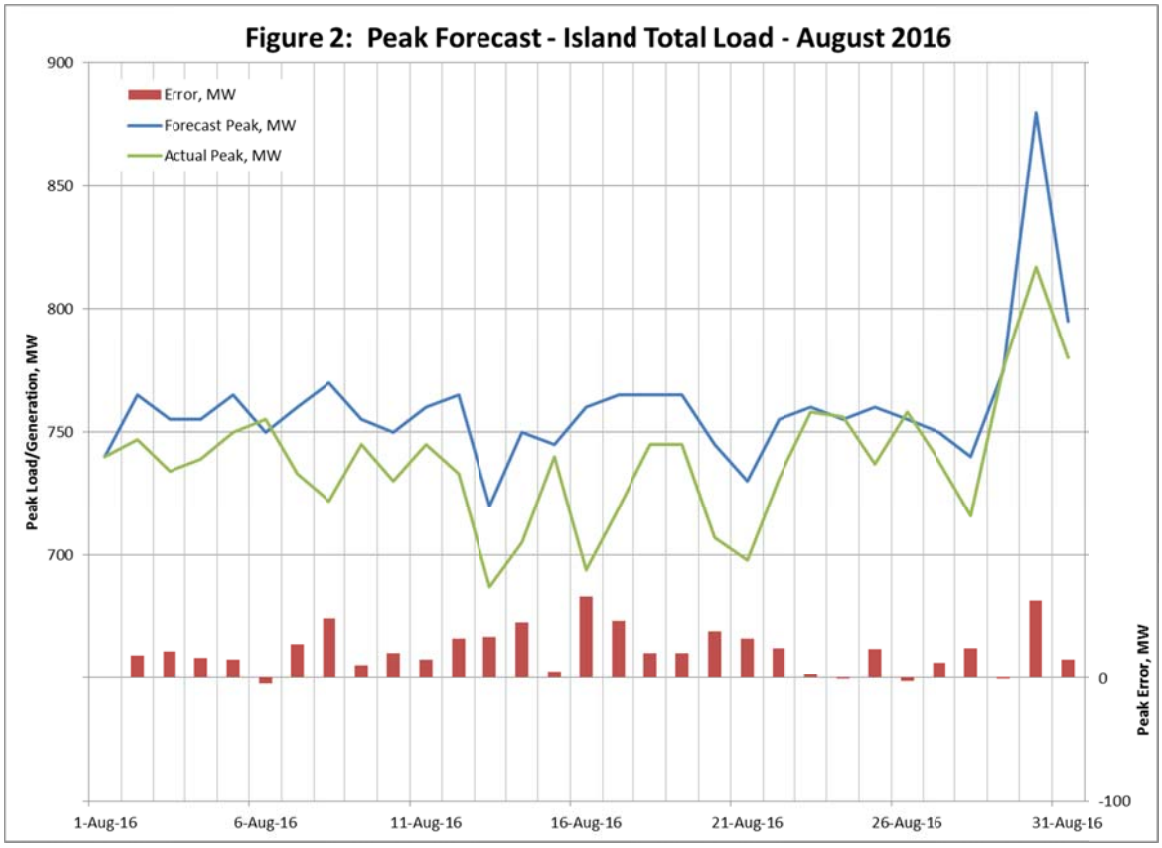


Figure 2: Peak Forecast - Island Total Load - August 2016
Error, MW
Forecast Peak, MW
Actual Peak, MW
Peak Load/Generation, MW
Peak Error, MW
900
850
800
750
700
0
-100
1-Aug-16
6-Aug-16
11-Aug-16
16-Aug-16
21-Aug-16
26-Aug-16
31-Aug-16

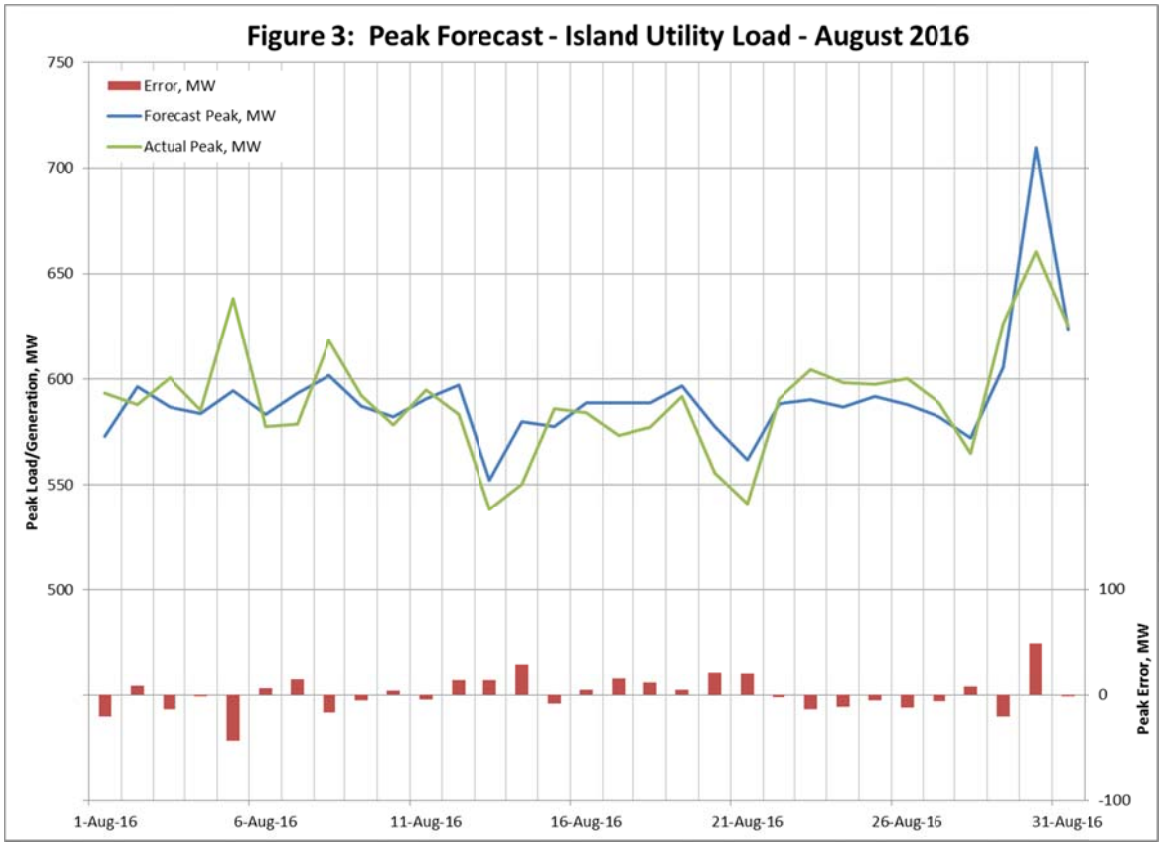


Figure 3: Peak Forecast - Island Utility Load - August 2016
Error, MW
Forecast Peak, MW
Actual Peak, MW
Peak Load/Generation, MW
Peak Error, MW
750
700
650
600
550
500
100
0
-100
1-Aug-16
6-Aug-16
11-Aug-16
16-Aug-16
21-Aug-16
26-Aug-16
31-Aug-16

2.2 Data Adjustment

There were three days in August when data required adjustment in the Nostradamus database so that in the future, when August 2016 data are used in training the forecasting model, Nostradamus will use a realistic value.

On August 1 and August 8 the Remote Terminal Unit at the Western Avalon terminal station was offline for part of the day, which resulted in incorrect calculation of the Avalon utility load[1]. System Operations replaced the erroneous values in Nostradamus for those hours by interpolation.

On August 26, work on Unit 7 at Bay d'Espoir prevented its generation from being recorded in Hydro's Energy Management System and therefore the Island load calculation lead to an incorrect value in the database. The value of generation was known, so it was added into the total load manually.

2.3 August 14, 2016

On August 14, the forecast peak at 7:20 am, as reported to the Board, was 750 MW; the actual reported peak was 705 MW. The absolute difference was 45 MW, 6.4% of the actual. Figure 4 includes an hourly plot of the load forecast for August 14 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 hourly forecast predicted a noon peak of 749 MW; the peak was not until 9:00 pm, and was 704 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 closer to the

[1] Calculated using telemetered transmission line flows.

actual load for most of the day; August 14 being one of the days when the CBPP load was lower than forecast by, on average, 14 MW. The hourly utility forecast predicted a noon peak of 580 MW; the actual utility peak was at noon, but was only 550 MW.

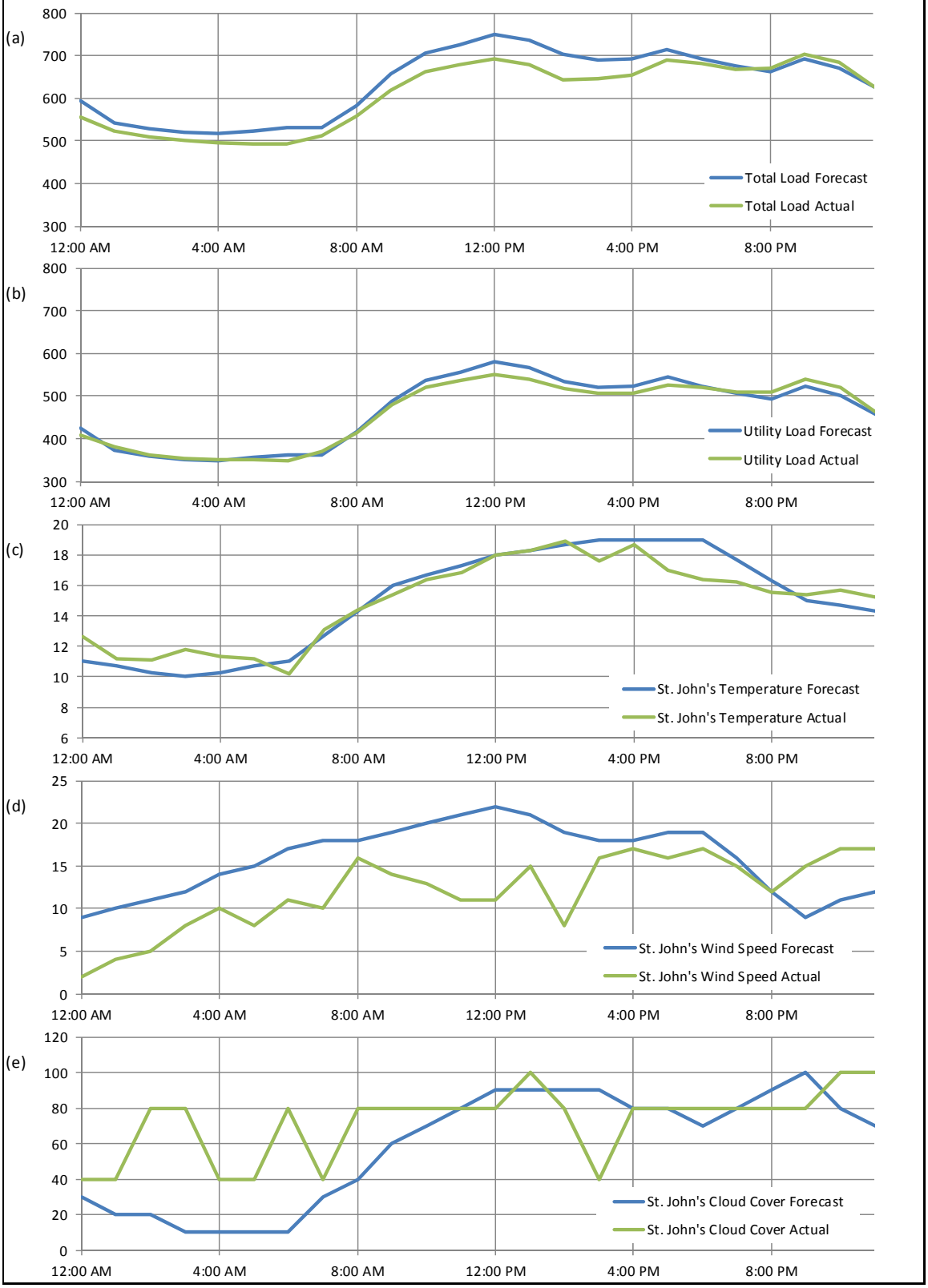
Figure 4(c) shows the actual temperature in St. John's compared to the forecast. The temperature forecast was very good for the part of the day prior to the peak, so errors in the temperature forecast do not explain the error in the load forecast.

Figure 4(d) shows the actual wind speed in St. John's compared to the forecast. For most of the day the wind forecast overestimated the wind speed which could possibly have contributed to an overestimate of the load. Figure 4(e) shows the actual cloud cover in St. John's compared to the forecast; it was relatively accurate for most of the day.

The relationship between load and weather is harder to predict during the summer. Up to a certain temperature load continues to drop as heating load reduces but as temperature continues to rise, air conditioning load could become a factor. Higher winds than forecast could possibly increase heat load or decrease air conditioning load. Relative humidity likely also influences load, but currently humidity is not considered by the Nostradamus models.

The discrepancy between actual and forecast utility load for August 14 was likely a result factors not modelled by Nostradamus. Energy Control Centre operators would have been aware of the lower than predicted CBPP load and would have responded accordingly. An overestimate of the load results in more than enough reserve being available. By the time of the peak the forecast had improved and was approximately 3% higher than the actual.

Figure 4 Accuracy Analysis - Aug 14, 2016



2.4 August 30, 2016

On August 30, the forecast peak at 7:20 am, as reported to the Board, was 880 MW; the actual reported peak was 817 MW. The absolute difference was 63 MW, 7.7% of the actual.

Figure 5(a) shows the hourly distribution of the load forecast compared to the actual load. The forecast overestimated the load for the whole day. The forecast was for a 5:00 pm peak of 879 MW, the actual peak occurred at 5:00 pm but was only 811 MW.

Figure 5(b) shows the hourly distribution of the utility load forecast only. The utility forecast was closer to the actual load for most of the day; August 30 being another of the days when the CBPP load was lower than forecast by up to 30 MW. The error in the peak of the utility forecast was 6.9%.

Figures 5(c) through 5(d) shows the actual temperature, wind and cloud cover in St. John's compared to the forecasts. In all cases the forecast was relatively accurate. At the time of the peak the temperature was quite low for August, at close to 10 degrees; the Nostradamus model may have anticipated that there would be a heating load at that temperature that did not transpire.

The discrepancy between actual and forecast utility load for August 30 may have been partly a result of unusual temperatures for the month and partly a result of other factors not modelled by Nostradamus. An overestimate of the load results in more than enough reserve being available. By the time of the peak the forecast had improved and was approximately 3% higher than the actual.

Figure 5 Accuracy Analysis - Aug 30, 2016