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October 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: September 2016.*

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

Yours truly,

NEWFOUNDLAND AND LABRADOR HYDRO

Tracey Pennell

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: September 2016

Newfoundland and Labrador Hydro

October 13, 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 SEPTEMBER 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 September 2016. The data are also presented in Figure 1. The actual peaks, as reported to the Board, varied from 737 MW on September 22 to 962 MW on September 29.

The available capacity during the month was between 1120 MW on September 14 and 1405 MW on September 17. Reserves were sufficient throughout the period.

Table 2 presents error statistics for the peak forecasts during the month of September 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 September the forecast peak was in a range between 3.8% below the actual peak and 11.8% 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 88 MW too high. On average, the forecast peak was 21 MW different than the actual peak, or 2.7%.

Figure 2 shows that the total island load was frequently overestimated through September. A review of the CBPP load shows that, again, it was below the forecasted 107 MW for much of the month. The average load was 95 MW, 12 MW 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 September 3, September 10, and September 15. In all cases both the total and utility-only forecast overestimated the load.

Table 1 Sep 2016 Load Forecasting Data

Date	Forecast Peak, MW	Actual Peak, MW	Available Island Supply, MW	Forecast Reserve, MW
1-Sep-16	780	751	1320	540
2-Sep-16	785	799	1345	560
3-Sep-16	835	747	1325	490
4-Sep-16	820	794	1330	510
5-Sep-16	765	760	1355	590
6-Sep-16	755	776	1345	590
7-Sep-16	775	756	1335	560
8-Sep-16	815	797	1340	525
9-Sep-16	795	793	1330	535
10-Sep-16	845	765	1305	460
11-Sep-16	790	785	1265	475
12-Sep-16	805	759	1380	575
13-Sep-16	760	747	1345	585
14-Sep-16	780	772	1120	340
15-Sep-16	890	830	1375	485
16-Sep-16	830	822	1365	535
17-Sep-16	750	740	1405	655
18-Sep-16	755	768	1385	630
19-Sep-16	920	872	1370	450
20-Sep-16	860	851	1185	325
21-Sep-16	790	783	1170	380
22-Sep-16	745	737	1250	505
23-Sep-16	785	790	1170	385
24-Sep-16	810	807	1285	475
25-Sep-16	860	846	1270	410
26-Sep-16	930	912	1240	310
27-Sep-16	900	905	1255	355
28-Sep-16	915	925	1280	365
29-Sep-16	925	962	1300	375
30-Sep-16	945	954	1340	395
Minimum	745	737	1120	310
Average	824	810	1303	479
Maximum	945	962	1405	655

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

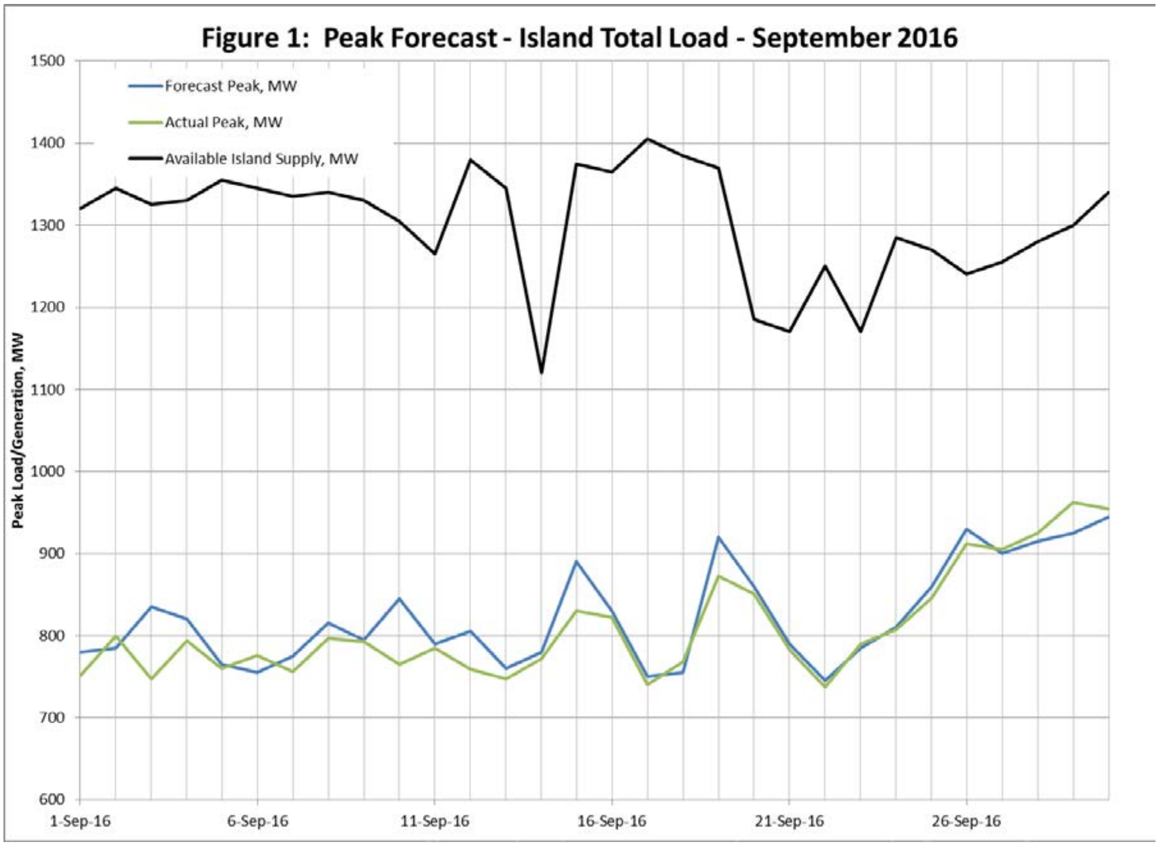


Figure 1: Peak Forecast - Island Total Load - September 2016
Forecast Peak, MW
Actual Peak, MW
Available Island Supply, MW
Peak Load/Generation, MW
1500
1400
1300
1200
1100
1000
900
800
700
600
1-Sep-16
6-Sep-16
11-Sep-16
16-Sep-16
21-Sep-16
26-Sep-16

Table 2 Sep 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-Sep-16	751	780	29	29	3.9%	3.9%	3.7%
2-Sep-16	799	785	-14	14	-1.8%	1.8%	-1.8%
3-Sep-16	747	835	88	88	11.8%	11.8%	10.5%
4-Sep-16	794	820	26	26	3.3%	3.3%	3.2%
5-Sep-16	760	765	5	5	0.7%	0.7%	0.7%
6-Sep-16	776	755	-21	21	-2.7%	2.7%	-2.8%
7-Sep-16	756	775	19	19	2.5%	2.5%	2.5%
8-Sep-16	797	815	18	18	2.3%	2.3%	2.2%
9-Sep-16	793	795	2	2	0.3%	0.3%	0.3%
10-Sep-16	765	845	80	80	10.5%	10.5%	9.5%
11-Sep-16	785	790	5	5	0.6%	0.6%	0.6%
12-Sep-16	759	805	46	46	6.1%	6.1%	5.7%
13-Sep-16	747	760	13	13	1.7%	1.7%	1.7%
14-Sep-16	772	780	8	8	1.0%	1.0%	1.0%
15-Sep-16	830	890	60	60	7.2%	7.2%	6.7%
16-Sep-16	822	830	8	8	1.0%	1.0%	1.0%
17-Sep-16	740	750	10	10	1.4%	1.4%	1.3%
18-Sep-16	768	755	-13	13	-1.7%	1.7%	-1.7%
19-Sep-16	872	920	48	48	5.5%	5.5%	5.2%
20-Sep-16	851	860	9	9	1.1%	1.1%	1.0%
21-Sep-16	783	790	7	7	0.9%	0.9%	0.9%
22-Sep-16	737	745	8	8	1.1%	1.1%	1.1%
23-Sep-16	790	785	-5	5	-0.6%	0.6%	-0.6%
24-Sep-16	807	810	3	3	0.4%	0.4%	0.4%
25-Sep-16	846	860	14	14	1.7%	1.7%	1.6%
26-Sep-16	912	930	18	18	2.0%	2.0%	1.9%
27-Sep-16	905	900	-5	5	-0.6%	0.6%	-0.6%
28-Sep-16	925	915	-10	10	-1.1%	1.1%	-1.1%
29-Sep-16	962	925	-37	37	-3.8%	3.8%	-4.0%
30-Sep-16	954	945	-9	9	-0.9%	0.9%	-1.0%
Minimum	737	745	-37	2	-3.8%	0.3%	-4.0%
Average	810	824	14	21	1.8%	2.7%	1.6%
Maximum	962	945	88	88	11.8%	11.8%	10.5%

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.

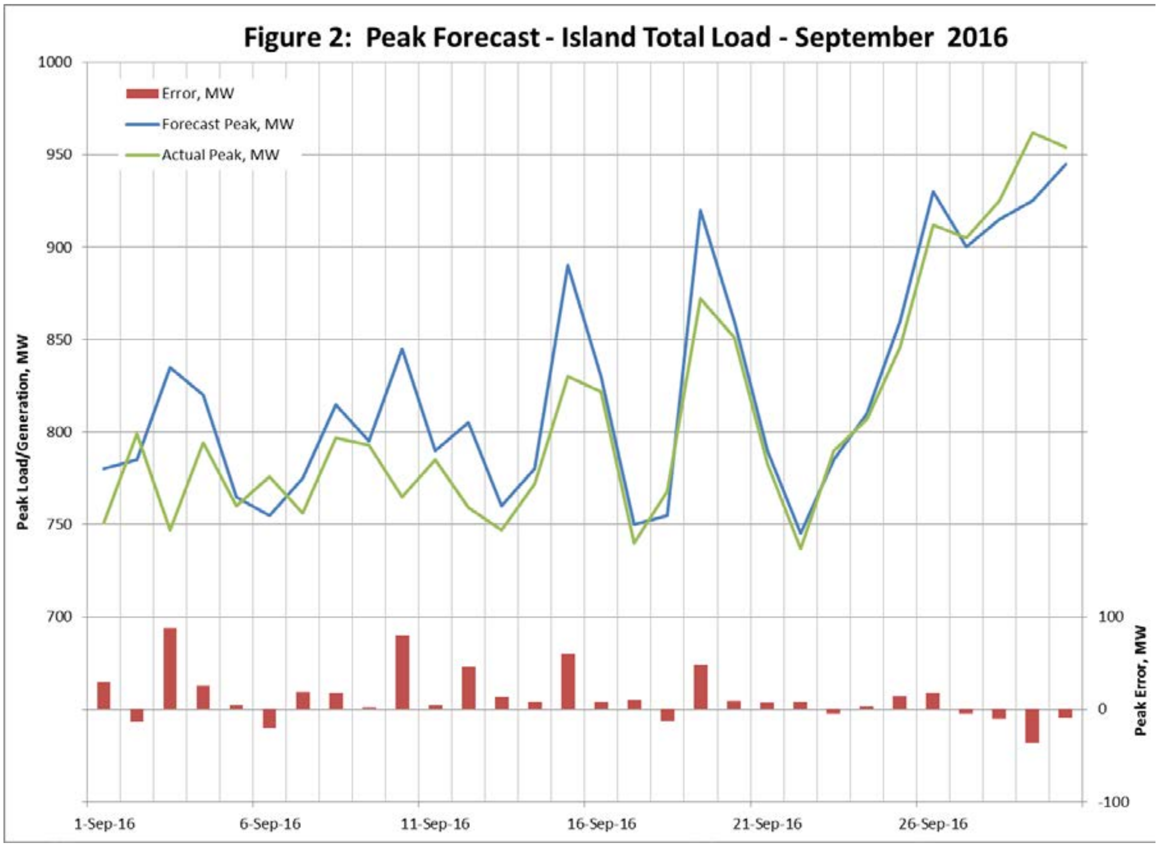


Figure 2: Peak Forecast - Island Total Load - September 2016
Error, MW
Forecast Peak, MW
Actual Peak, MW
Peak Load/Generation, MW
Peak Error, MW
1000
950
900
850
800
750
700
100
0
-100
1-Sep-16
6-Sep-16
11-Sep-16
16-Sep-16
21-Sep-16
26-Sep-16

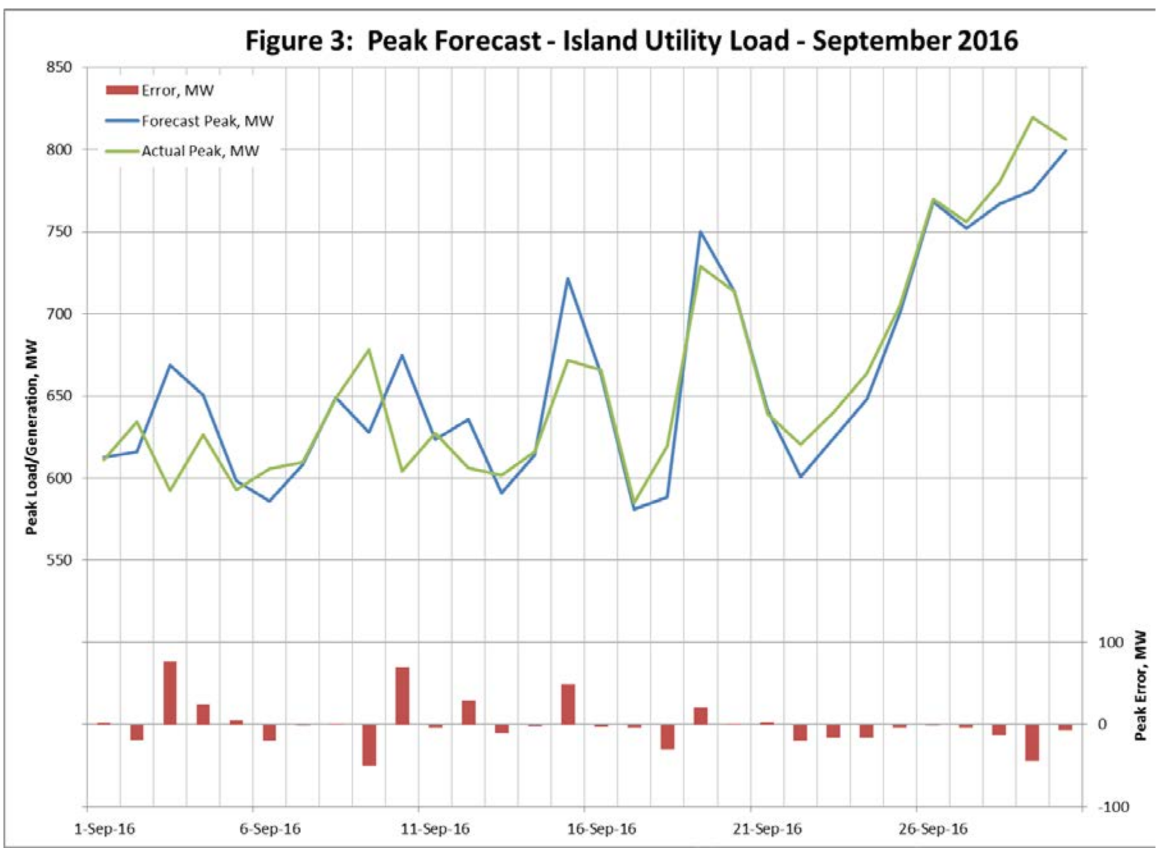


Figure 3: Peak Forecast - Island Utility Load - September 2016
Error, MW
Forecast Peak, MW
Actual Peak, MW
Peak Load/Generation, MW
Peak Error, MW
850
800
750
700
650
600
550
100
0
-100
1-Sep-16
6-Sep-16
11-Sep-16
16-Sep-16
21-Sep-16
26-Sep-16

2.2 Data Adjustment

On September 7, the actual total load was not calculated for two hours because of a database problem so the forecast value was input to prevent a gap in the data. Replacing the data meant that forecast accuracy was not affected, and in future, when the data is used for training, realistic load data will be used.

2.3 September 3, 2016

On September 3, the forecast peak at 7:20 am, as reported to the Board, was 835 MW; the actual reported peak was 747 MW. The absolute difference was 88 MW, 11.8% of the actual. Figure 4 includes an hourly plot of the load forecast for September 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 hourly forecast predicted a noon peak of 837 MW; the peak was actually at 10:00 am, and was 739 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 forecast utility load was somewhat closer to the actual utility load, especially later in the day and through the evening. Both the total and the utility forecasts predicted a strong midday peak; in actual fact the load was quite flat with three smaller, similar peaks in the late morning, the late afternoon and mid evening.

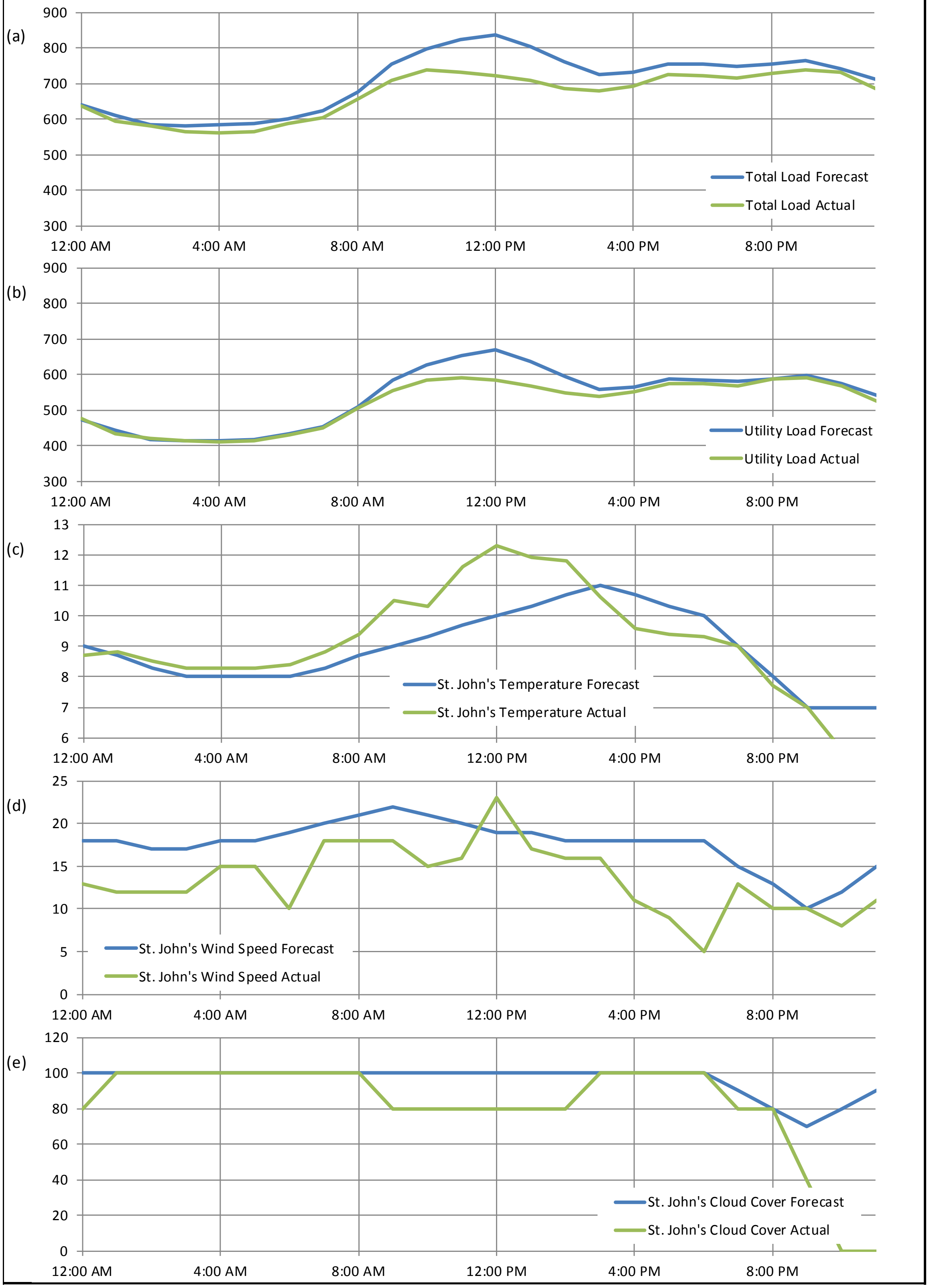
Figure 4(c) shows the actual temperature in St. John’s compared to the forecast. The temperature forecast was poor for most of the day with the actual midday temperature being 2 degrees higher than forecast, so errors in the temperature forecast may explain some of the error in the load forecast.

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 also 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 September 3 was a result of errors in the temperature and wind. An overestimate of the load results in more than enough reserve being available.

Figure 4 Accuracy Analysis - Sep 03, 2016



2.4 September 10, 2016

On September 10, the forecast peak at 7:20 am, as reported to the Board, was 845 MW; the actual reported peak was 765 MW. The absolute difference was 80 MW, 10.5% of the actual load. Figure 5 includes an hourly plot of the load forecast for September 10 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 overestimated the load for the whole day. The forecast was for a 1:00 pm peak of 843 MW; the actual peak occurred at 8:00 pm and was only 759 MW.

Figure 5(b) shows the hourly distribution of the utility load forecast only. The forecast utility load was somewhat closer to the actual load for most of the day. Again Nostradamus predicted a midday peak but the load was quite flat, with three smaller peaks in the late morning, the late afternoon and mid evening.

Figures 5(c) through 5(d) shows the actual temperature, wind and cloud cover in St. John's compared to the forecasts. The temperature during the late morning was lower than forecast so if heating load were a factor the forecast should have underestimated the peak. The temperature trend on September 10 was unusual – the daily high temperature occurred at midnight and the temperature steadily decreased during the day. It has been noted in the past that the Nostradamus forecasts tend to be less accurate when the temperature trend is unusual.

The wind and cloud cover forecasts were relatively accurate.

It is difficult to know why the forecast was erroneous on September 10; it was likely due to factors not modelled by Nostradamus. It has been noted in the past that the Nostradamus forecasts tend to be less accurate when the temperature pattern through the day is unusual and when the peak is at an unusual time, in this case in mid evening. 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 4% higher than the actual.

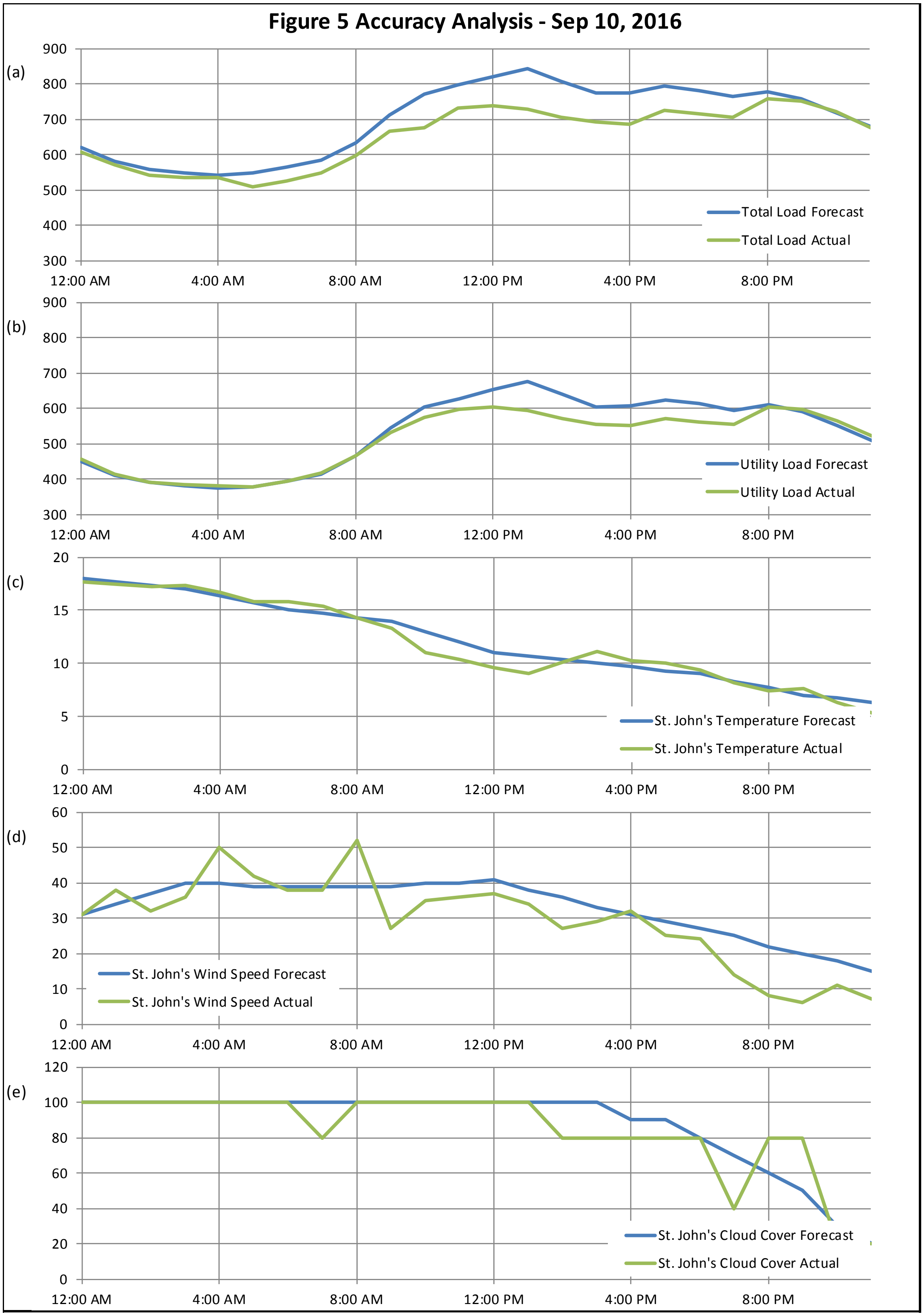


Figure 5 Accuracy Analysis - Sep 10, 2016
(a)
900
800
700
600
500
400
300
Total Load Forecast
Total Load Actual
12:00 AM
4:00 AM
8:00 AM
12:00 PM
4:00 PM
8:00 PM
(b)
Utility Load Forecast
Utility Load Actual
(c)
20
15
10
5
0
St. John's Temperature Forecast
St. John's Temperature Actual
(d)
60
50
40
30
20
10
St. John's Wind Speed Forecast
St. John's Wind Speed Actual
(e)
120
100
80
60
40
20
St. John's Cloud Cover Forecast
St. John's Cloud Cover Actual

2.5 September 15, 2016

On September 15, the forecast peak at 7:20 am, as reported to the Board, was 890 MW; the actual reported peak was 830 MW. The absolute difference was 60 MW, 7.2% of the actual.

Figure 6 includes an hourly plot of the load forecast for September 15 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 forecast overestimated the load for the whole day. The forecast was for a 8:00 pm peak of 889 MW; the peak did occur at 8:00 pm but was only 825 MW.

Figure 6(b) shows the hourly distribution of the utility load forecast only. The forecast utility load was generally closer to the actual load for most of the day, but percentagewise, the error in the peak was similar.

Figures 6(c) through 6(d) shows the actual temperature, wind and cloud cover in St. John's compared to the forecasts. The temperature during the afternoon and early evening was lower than forecast, which, if heating load were a factor, should have led to an underestimate of the peak; but the actual wind speed was lower than forecast which would have had an opposite effect. As on September 10, the temperature trend on September 15 was unusual which may have contributed to the forecast error. The cloud cover forecast was relatively accurate.

It is difficult to know why the forecast was erroneous on September 15; it was likely due to factors not modelled by Nostradamus. It has been noted in the past that the Nostradamus forecasts tend to be less accurate when the temperature pattern through the day is unusual and when the peak is at an unusual time, in this case in mid evening.

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 6 Accuracy Analysis - Sep 15, 2016