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October 13, 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: September 2015.*

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

Yours truly,

NEWFOUNDLAND AND LABRADOR HYDRO

Tracey L. Pennell
Legal Counsel

TLP/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: September 2015

Newfoundland and Labrador Hydro

October 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 (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 April 1, 2012 to March 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 period are input at approximately 5 am and again at mid-day (1 pm or 2 pm depending on Daylight Saving Time). Nostradamus is run every hour of the day and the most recent load 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 load 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 SEPTEMBER 2015 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 2015. The data are also presented in Figure 1. The actual peaks, as reported to the Board, varied from 722 MW on September 6 to 983 MW on September 27.

The available capacity during the month was between 1185 MW on September 1 and 1365 MW on September 8. Reserves were sufficient throughout the period.

Table 2 presents error statistics for the peak forecasts during the month of September 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.[3]

As noted in the August Nostradamus Accuracy report, the CBPP load during August was significantly below the default forecast of 107 MW which led to significant apparent error (overestimate) in the forecast. The CBPP load was closer to normal through September, with an average load over the month of 99 MW, but was still below the power-on-order by up to 50 MW for short periods. 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.

Through the month of September the forecast peak was in a range between 5.0% below the actual peak and 9.3% above the actual peak. The days of greatest discrepancies between the forecast and actual peaks were all overestimates. On the best days the forecast peak was essentially the same as the actual peak; on the worst day it was 79 MW too high. On average, the forecast peak was 21 MW different than the actual peak, or 2.6% of actual.

In the review of forecast accuracy statistics for September 2015 in Table 2, Hydro offers further detail on the difference found between forecast and actual peak for September 16 and September 18.

Table 1 September 2015 Load Forecasting Data

Date	Forecast Peak, MW	Actual Peak, MW	Available Island Supply, MW	Forecast Reserve, MW
1-Sep-15	775	754	1185	410
2-Sep-15	785	780	1205	420
3-Sep-15	790	761	1215	425
4-Sep-15	785	758	1230	445
5-Sep-15	755	744	1230	475
6-Sep-15	765	722	1225	460
7-Sep-15	780	778	1355	575
8-Sep-15	805	847	1365	560
9-Sep-15	870	852	1210	340
10-Sep-15	805	776	1225	420
11-Sep-15	765	747	1215	450
12-Sep-15	770	780	1260	490
13-Sep-15	755	752	1280	525
14-Sep-15	830	810	1260	430
15-Sep-15	810	802	1250	440
16-Sep-15	925	846	1270	345
17-Sep-15	860	847	1300	440
18-Sep-15	880	826	1270	390
19-Sep-15	765	788	1305	540
20-Sep-15	745	765	1315	570
21-Sep-15	795	803	1290	495
22-Sep-15	815	805	1300	485
23-Sep-15	825	809	1260	435
24-Sep-15	775	776	1290	515
25-Sep-15	855	829	1285	430
26-Sep-15	925	904	1300	375
27-Sep-15	975	983	1235	260
28-Sep-15	835	793	1310	475
29-Sep-15	769	760	1270	501
30-Sep-15	775	786	1290	515
Minimum	745	722	1185	260
Average	812	799	1267	455
Maximum	975	983	1365	575

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).

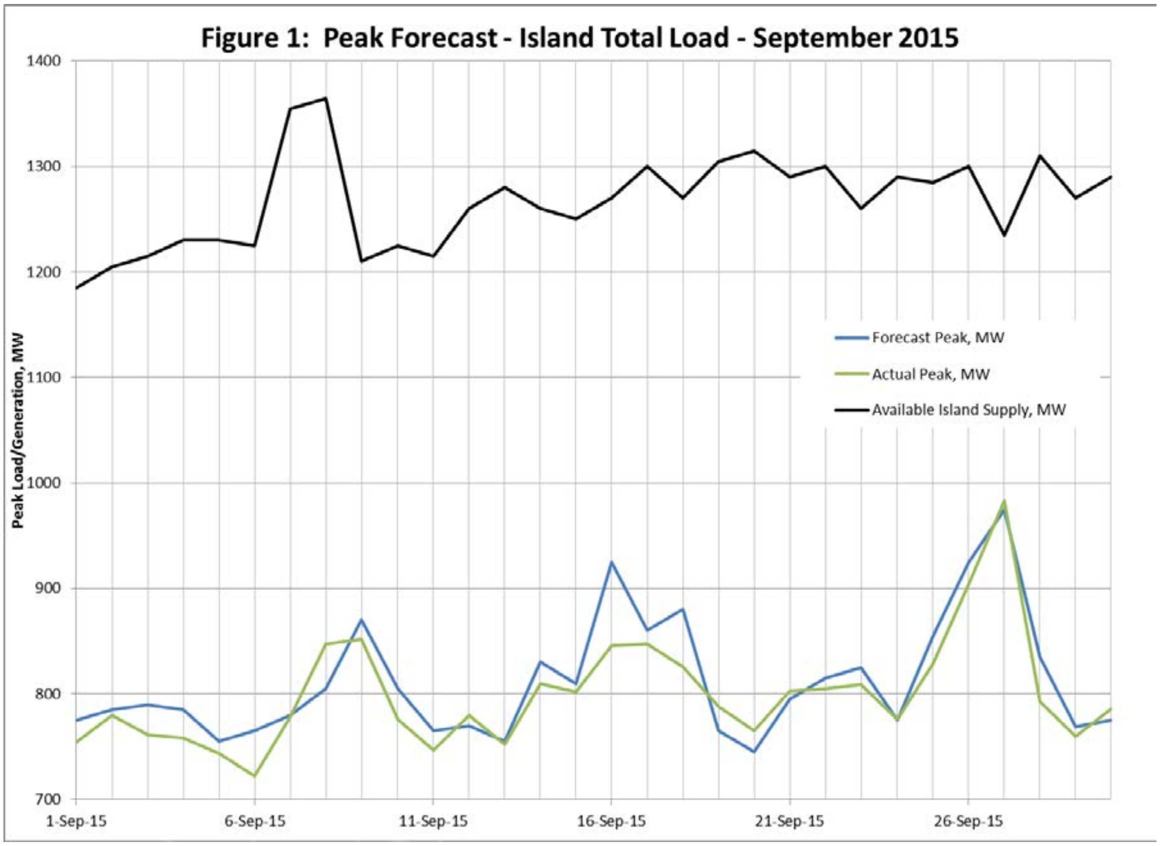


Figure 1: Peak Forecast - Island Total Load - September 2015
1400
1300
1200
1100
1000
900
800
700
Peak Load/Generation, MW
1-Sep-15
6-Sep-15
11-Sep-15
16-Sep-15
21-Sep-15
26-Sep-15
Forecast Peak, MW
Actual Peak, MW
Available Island Supply, MW

Table 2 September 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-Sep-15	754	775	21	21	2.8%	2.8%	2.7%
2-Sep-15	780	785	5	5	0.6%	0.6%	0.6%
3-Sep-15	761	790	29	29	3.8%	3.8%	3.7%
4-Sep-15	758	785	27	27	3.6%	3.6%	3.4%
5-Sep-15	744	755	11	11	1.5%	1.5%	1.5%
6-Sep-15	722	765	43	43	6.0%	6.0%	5.6%
7-Sep-15	778	780	2	2	0.3%	0.3%	0.3%
8-Sep-15	847	805	-42	42	-5.0%	5.0%	-5.2%
9-Sep-15	852	870	18	18	2.1%	2.1%	2.1%
10-Sep-15	776	805	29	29	3.7%	3.7%	3.6%
11-Sep-15	747	765	18	18	2.4%	2.4%	2.4%
12-Sep-15	780	770	-10	10	-1.3%	1.3%	-1.3%
13-Sep-15	752	755	3	3	0.4%	0.4%	0.4%
14-Sep-15	810	830	20	20	2.5%	2.5%	2.4%
15-Sep-15	802	810	8	8	1.0%	1.0%	1.0%
16-Sep-15	846	925	79	79	9.3%	9.3%	8.5%
17-Sep-15	847	860	13	13	1.5%	1.5%	1.5%
18-Sep-15	826	880	54	54	6.5%	6.5%	6.1%
19-Sep-15	788	765	-23	23	-2.9%	2.9%	-3.0%
20-Sep-15	765	745	-20	20	-2.6%	2.6%	-2.7%
21-Sep-15	803	795	-8	8	-1.0%	1.0%	-1.0%
22-Sep-15	805	815	10	10	1.2%	1.2%	1.2%
23-Sep-15	809	825	16	16	2.0%	2.0%	1.9%
24-Sep-15	776	775	-1	1	-0.1%	0.1%	-0.1%
25-Sep-15	829	855	26	26	3.1%	3.1%	3.0%
26-Sep-15	904	925	21	21	2.3%	2.3%	2.3%
27-Sep-15	983	975	-8	8	-0.8%	0.8%	-0.8%
28-Sep-15	793	835	42	42	5.3%	5.3%	5.0%
29-Sep-15	760	769	9	9	1.2%	1.2%	1.2%
30-Sep-15	786	775	-11	11	-1.4%	1.4%	-1.4%
Minimum	722	745	-42	1	-5.0%	0.1%	-5.2%
Average	799	812	13	21	1.6%	2.6%	1.5%
Maximum	983	975	79	79	9.3%	9.3%	8.5%

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.

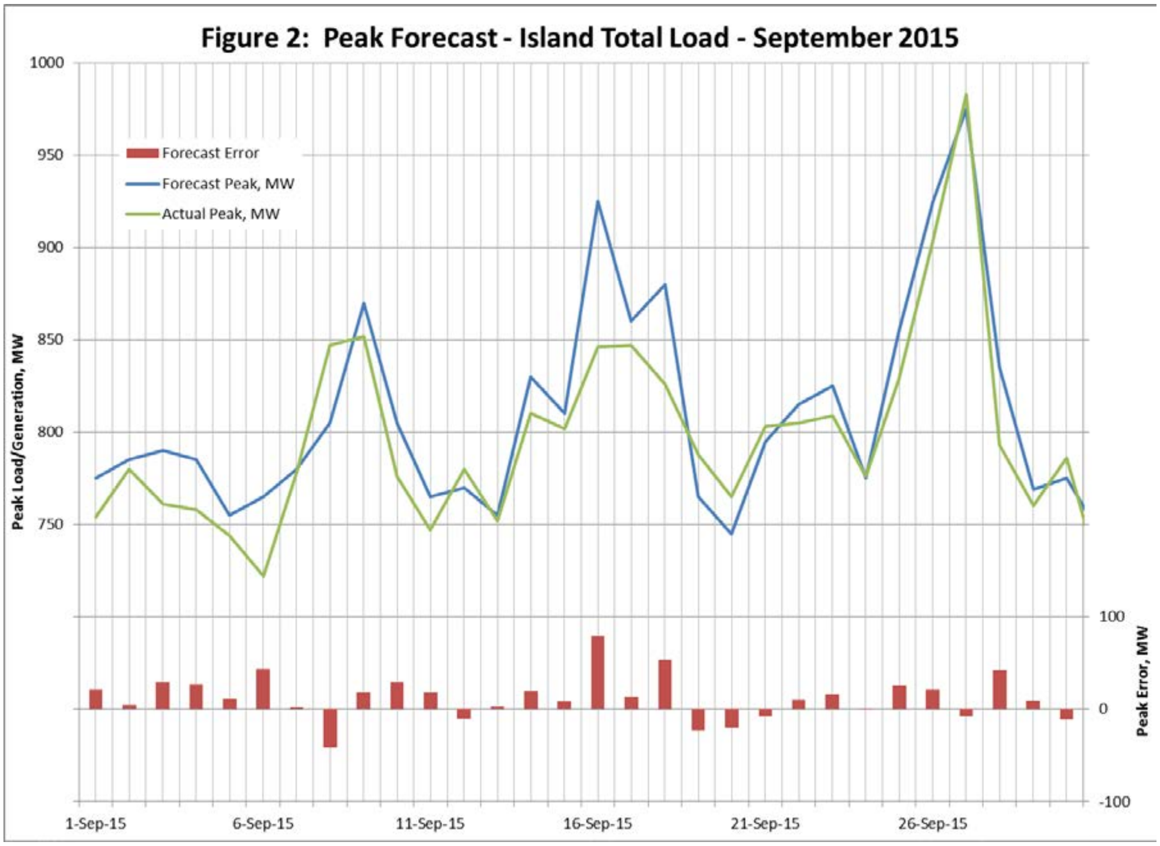


Figure 2: Peak Forecast - Island Total Load - September 2015
1000
950
900
850
800
750
Peak Load/Generation, MW
Forecast Error
Forecast Peak, MW
Actual Peak, MW
100
0
-100
Peak Error, MW
1-Sep-15
6-Sep-15
11-Sep-15
16-Sep-15
21-Sep-15
26-Sep-15

2.2 September 6, 2015

On September 6, the forecast peak at 7:20 am was 765 MW; the actual reported peak was 722 MW. The absolute difference was 43 MW, 6.0% of the actual. Figure 3 includes an hourly plot of the load forecast for September 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 shape of the actual load was very similar to forecast but was generally lower. The forecast predicted a 10 am peak of 765 MW. The actual peak was close to 10 am but was only 722 MW (the plot shows a peak of 717 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.

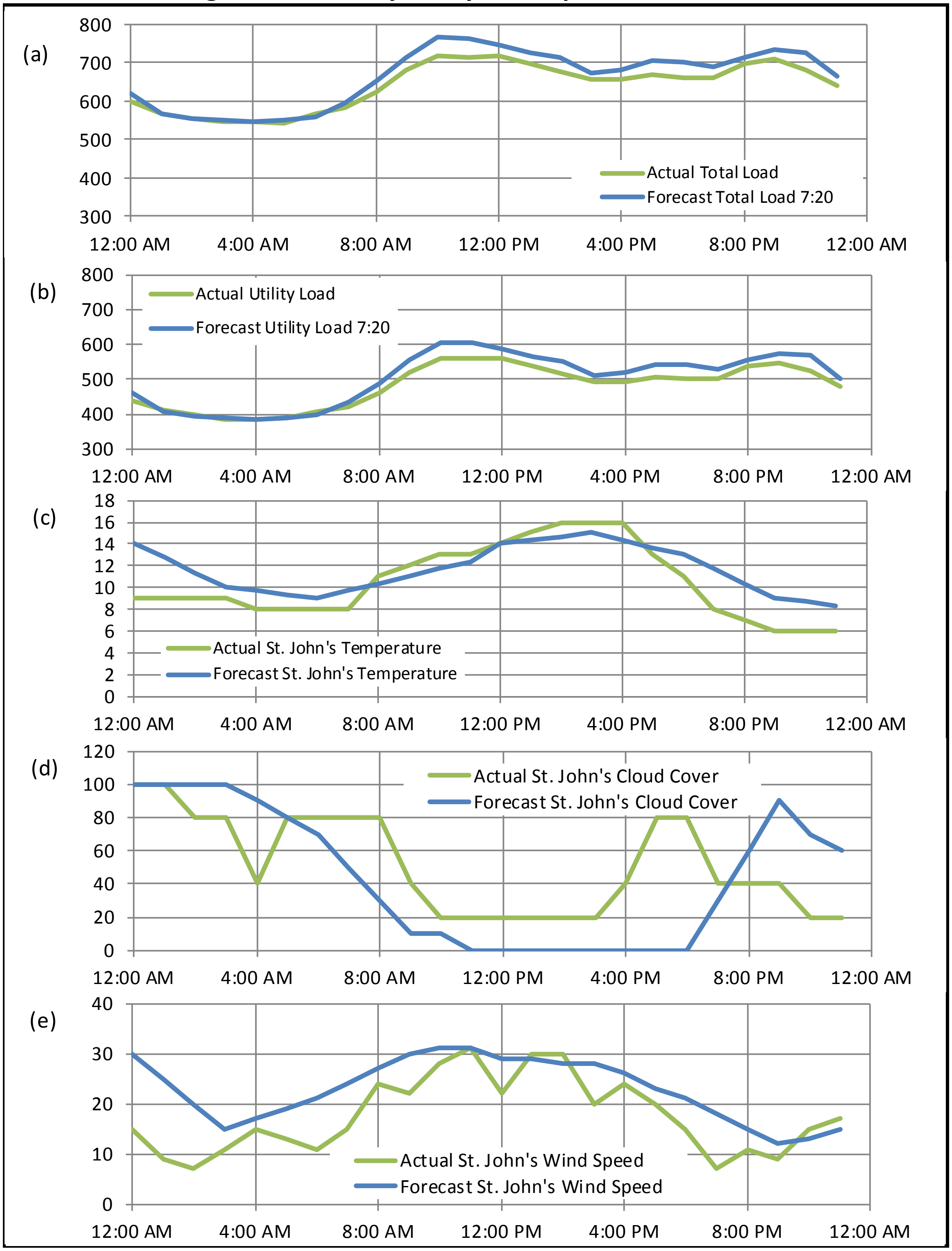
Figure 3(c) shows the actual temperature in St. John's compared to the forecast. Although Nostradamus uses weather data at four sites, the weather in St. John's tends to have the largest effect because of the concentration of customers in St. John's. The temperature forecast was quite accurate for the day. At the time of the peak the actual temperature was one or two degrees above forecast so that may have contributed somewhat to the load being lower than 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 which would generally lead to a load higher than forecast, so the error in the cloud cover forecast did not contribute the to the load forecast error.

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 lower than predicted so the error in the wind speed forecast may have contributed somewhat to the over forecast of the peak.

It is difficult to ascertain why Nostradamus overestimated the load for most of September 6. Errors in the weather forecast likely contributed somewhat but other factors, not modelled by Nostradamus, may also have also contributed to the forecast error. By the time of the peak, the forecast had improved and was only 4% above actual. The fact that the error was positive, i.e. the load was lower than forecast, means that reserves were greater than predicted.

Figure 3 Accuracy Analysis - September 6, 2015



2.3 September 16, 2015

On September 16, the forecast peak at 7:20 am was 925 MW; the actual reported peak was 846 MW. The absolute difference was 79 MW, 9.3% of the actual. Figure 4 includes an hourly plot of the load forecast for September 16 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 a 5 pm peak of 925 MW. The actual peak was 846 MW at 7:55 pm (the plot shows a peak of 842 MW as it was created with data from Nostradamus which is input on the hour only). The forecast at the time of the peak was quite accurate (a difference of only 2.8%), but Nostradamus predicted a higher late-afternoon peak that did not occur.

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 88 MW, approximately 20 MW below the power-on-order, so this contributed to the variance in the peak.

Figures 4(c) through 4(e) show the actual temperatures, cloud cover and wind speeds in St. John's compared to the forecasts. 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 forecasts were quite accurate through the afternoon and evening so error in the weather forecast did not contribute to the load over forecast.

It is difficult to ascertain why Nostradamus underestimated the utility load for most of September 16. The total forecast was high because of the lower CBPP load, but the weather forecast was quite accurate so one would have expected the utility load to be accurate. Peaks late in the day, i.e. not during the morning or late-afternoon peaks, are unusual, so Nostradamus would not have had as many examples of load patterns like this on which to base its estimate. The load forecast at the time of the peak was quite accurate but Nostradamus predicted a higher late-afternoon peak that did not occur.

The Nostradamus model runs every hour to use actual loads experienced that day to improve the estimate for the rest of the day. Figure 5 shows the load forecasts at 7:20 am, 10:20 am, 1:20 pm, 4:20 pm and 7:20 pm. By 1:20 pm, the forecast utility peak was 714 MW, 2% above actual. The total forecast was 873 MW, 31 MW, or 4% above actual because of the error in the industrial load. These with-in day updates are used by Energy Control Centre operators to manage spinning reserve. An overestimate of the peak results in more than enough available reserve.

Figure 4 Accuracy Analysis - September 16, 2015

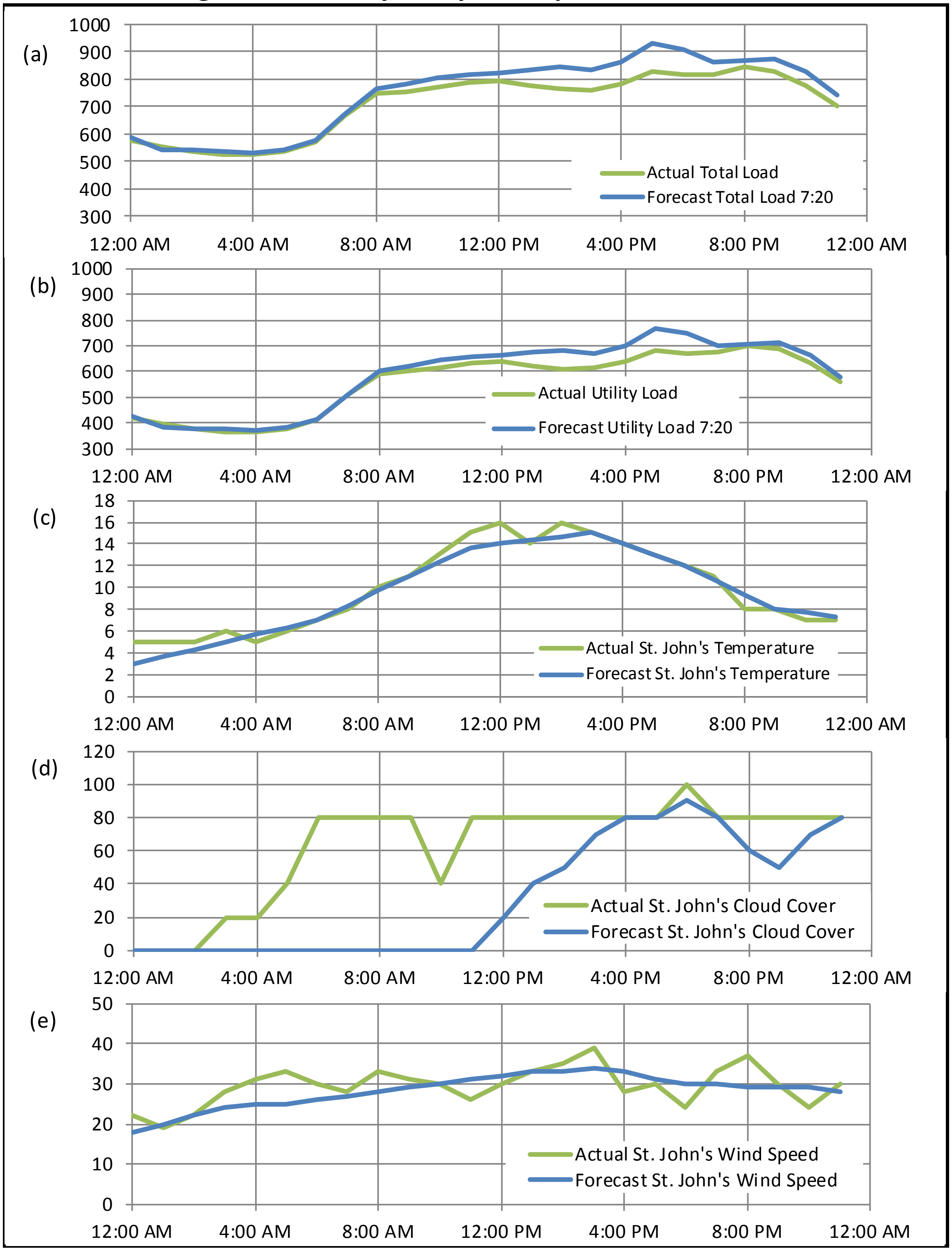
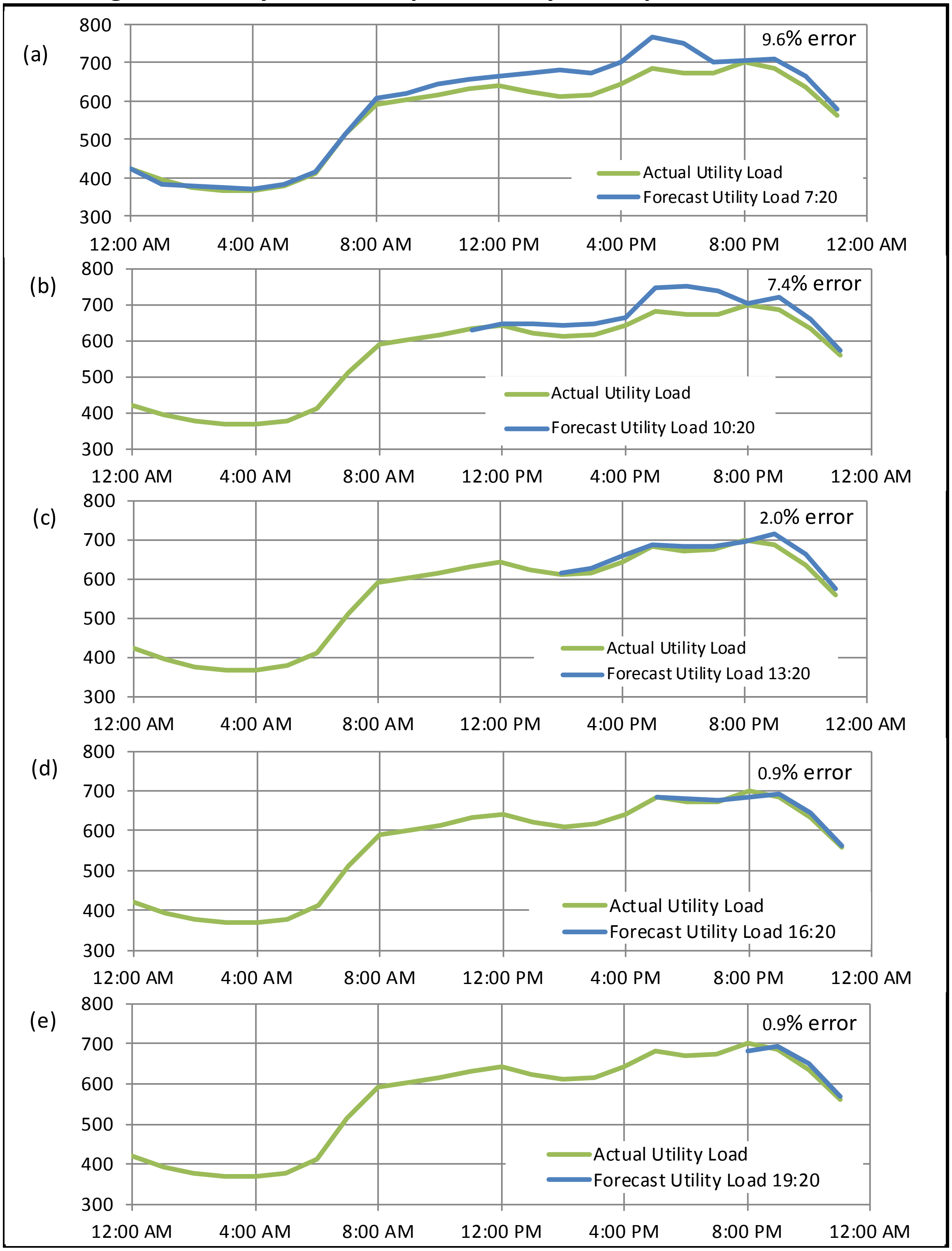


Figure 5 Utility Forecast Update Analysis - September 16, 2015



2.4 September 18, 2015

On September 18, the forecast peak at 7:20 am was 880 MW; the actual reported peak was 826 MW. The absolute difference was 54 MW, 6.5% of the actual. Figure 6 includes an hourly plot of the load forecast for September 18 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 predicted a 5 pm peak of 881 MW. The actual peak was 826 MW (the plot shows a peak of 814 MW as it was created with data from Nostradamus which is input on the hour only) at close to 8 pm. The forecast at the time of the peak was quite accurate (a difference of only 1.7%), but Nostradamus predicted a higher late-afternoon peak that did not occur.

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 that of the total load, so a discrepancy in the industrial forecast does not explain the variance in the peak.

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. The temperature was forecast to be approximately one or two degrees higher during the afternoon and evening than it actually was, so the error in the temperature forecast would have led to an underestimate, not an over estimate in the peak load forecast. However, the temperature pattern on this day was unusual. Instead of a typical warming then cooling trend, the temperature gradually decreased over the course of the day. It has been noted before that Nostradamus has had higher than usual error on days with unusual temperature patterns.

Figure 6(d) shows the actual cloud cover in St. John's compared to the forecast. For most of the day, the weather was as forecast. Figure 6(e) shows the actual wind speed in St. John's compared to the forecast. For most of the afternoon the actual wind speed was slightly lower than predicted so the error in the wind speed forecast may have contributed somewhat to the over forecast of the peak.

It is difficult to ascertain why Nostradamus underestimated the load for most of September 18. Errors in the weather forecast likely contributed somewhat to the underestimate but other factors, not modelled by Nostradamus, may also have contributed to the discrepancy. As noted for September 16, peaks late in the day are relatively unusual, so Nostradamus would not have had as many examples of load patterns like this on which to base its estimate. The forecast at the time of the peak was quite accurate but Nostradamus predicted a higher late-afternoon peak that did not occur.

The Nostradamus model runs every hour to use actual loads experienced that day to improve the estimate for the rest of the day. By 1:20 pm, the forecast utility peak for September 18 was 674 MW, 8 MW, or only 1.2%, above actual. The total forecast peak at 1:20 pm was 834 MW, 20 MW, or 2.5%, above actual. These with-in day updates are used by Energy Control Centre operators to manage spinning reserve. An overestimate of the peak results in more than enough available reserve.

Figure 6 Accuracy Analysis - September 18, 2015