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August 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: July 2016.*

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

Yours truly,

NEWFOUNDLAND AND LABRADOR HYDRO

for
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: July 2016

Newfoundland and Labrador Hydro

August 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 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 JULY 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 July 2016. The data are also presented in Figure 1. The actual peaks, as reported to the Board, varied from 705 MW on July 2 to 894 MW on July 11.

The available capacity during the month was between 1035 MW on July 15 and 1275 MW on July 5. Reserves were sufficient throughout the period.

Table 2 presents error statistics for the peak forecasts during the month of July 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 July the forecast peak was in a range between 3.2% below the actual peak and 8.7% 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 63 MW too high. On average, the forecast peak was 19 MW different than the actual peak, or 2.5%.

Figure 2 shows that there was a consistent overestimation of the total island load through July. A review of the Kruger load shows that it was below the forecasted 107 MW for much of the month. The average load was 93 MW, 14 MW below the forecast of 107 MW, but at times the load dipped below 40 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 forecast for July 2 when the forecast overestimated the peak by 45 MW or 6.4%, and July 5 when the forecast overestimated the peak by 63 MW, or by 8.7%.

Table 1 Jul 2016 Load Forecasting Data

Date	Forecast Peak, MW	Actual Peak, MW	Available Island Supply, MW	Forecast Reserve, MW
1-Jul-16	765	740	1270	505
2-Jul-16	750	705	1250	500
3-Jul-16	780	745	1245	465
4-Jul-16	790	764	1260	470
5-Jul-16	790	727	1275	485
6-Jul-16	860	832	1240	380
7-Jul-16	880	866	1245	365
8-Jul-16	860	828	1195	335
9-Jul-16	765	736	1210	445
10-Jul-16	785	791	1220	435
11-Jul-16	865	894	1230	365
12-Jul-16	875	875	1195	320
13-Jul-16	860	862	1190	330
14-Jul-16	815	781	1075	260
15-Jul-16	785	776	1035	250
16-Jul-16	750	720	1115	365
17-Jul-16	740	712	1205	465
18-Jul-16	780	781	1200	420
19-Jul-16	765	753	1155	390
20-Jul-16	750	736	1135	385
21-Jul-16	770	737	1170	400
22-Jul-16	760	748	1145	385
23-Jul-16	720	724	1215	495
24-Jul-16	735	723	1225	490
25-Jul-16	765	752	1170	405
26-Jul-16	760	762	1185	425
27-Jul-16	770	737	1180	410
28-Jul-16	780	774	1190	410
29-Jul-16	765	760	1190	425
30-Jul-16	730	733	1210	480
31-Jul-16	720	720	1215	495
Minimum	720	705	1035	250
Average	778	768	1195	411
Maximum	880	894	1275	505

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

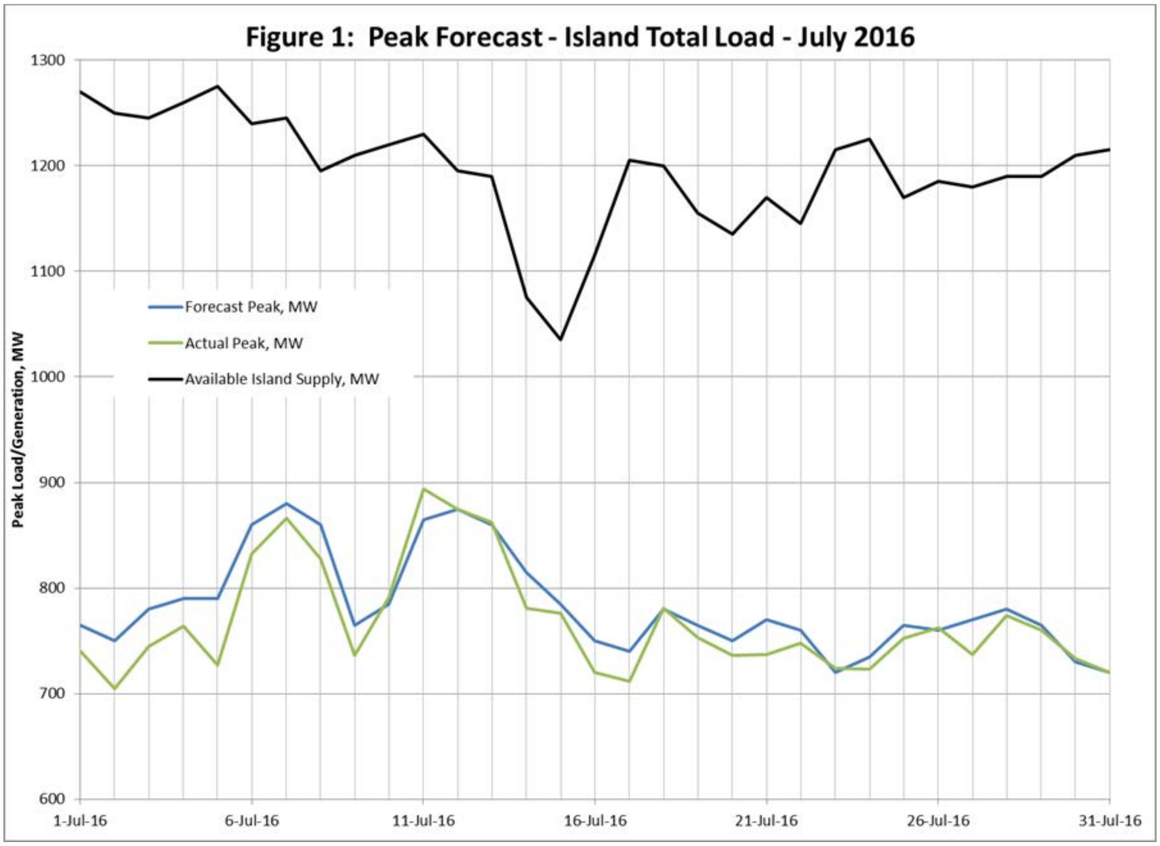


Figure 1: Peak Forecast - Island Total Load - July 2016
Peak Load/Generation, MW
1300
1200
1100
1000
900
800
700
600
1-Jul-16
6-Jul-16
11-Jul-16
16-Jul-16
21-Jul-16
26-Jul-16
31-Jul-16
Forecast Peak, MW
Actual Peak, MW
Available Island Supply, MW

Table 2 Jul 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-Jul-16	740	765	25	25	3.4%	3.4%	3.3%
2-Jul-16	705	750	45	45	6.4%	6.4%	6.0%
3-Jul-16	745	780	35	35	4.7%	4.7%	4.5%
4-Jul-16	764	790	26	26	3.4%	3.4%	3.3%
5-Jul-16	727	790	63	63	8.7%	8.7%	8.0%
6-Jul-16	832	860	28	28	3.4%	3.4%	3.3%
7-Jul-16	866	880	14	14	1.6%	1.6%	1.6%
8-Jul-16	828	860	32	32	3.9%	3.9%	3.7%
9-Jul-16	736	765	29	29	3.9%	3.9%	3.8%
10-Jul-16	791	785	-6	6	-0.8%	0.8%	-0.8%
11-Jul-16	894	865	-29	29	-3.2%	3.2%	-3.4%
12-Jul-16	875	875	0	0	0.0%	0.0%	0.0%
13-Jul-16	862	860	-2	2	-0.2%	0.2%	-0.2%
14-Jul-16	781	815	34	34	4.4%	4.4%	4.2%
15-Jul-16	776	785	9	9	1.2%	1.2%	1.1%
16-Jul-16	720	750	30	30	4.2%	4.2%	4.0%
17-Jul-16	712	740	28	28	3.9%	3.9%	3.8%
18-Jul-16	781	780	-1	1	-0.1%	0.1%	-0.1%
19-Jul-16	753	765	12	12	1.6%	1.6%	1.6%
20-Jul-16	736	750	14	14	1.9%	1.9%	1.9%
21-Jul-16	737	770	33	33	4.5%	4.5%	4.3%
22-Jul-16	748	760	12	12	1.6%	1.6%	1.6%
23-Jul-16	724	720	-4	4	-0.6%	0.6%	-0.6%
24-Jul-16	723	735	12	12	1.7%	1.7%	1.6%
25-Jul-16	752	765	13	13	1.7%	1.7%	1.7%
26-Jul-16	762	760	-2	2	-0.3%	0.3%	-0.3%
27-Jul-16	737	770	33	33	4.5%	4.5%	4.3%
28-Jul-16	774	780	6	6	0.8%	0.8%	0.8%
29-Jul-16	760	765	5	5	0.7%	0.7%	0.7%
30-Jul-16	733	730	-3	3	-0.4%	0.4%	-0.4%
31-Jul-16	720	720	0	0	0.0%	0.0%	0.0%
Minimum	705	720	-29	0	-3.2%	0.0%	-3.4%
Average	768	778	16	19	2.1%	2.5%	2.0%
Maximum	894	880	63	63	8.7%	8.7%	8.0%

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.

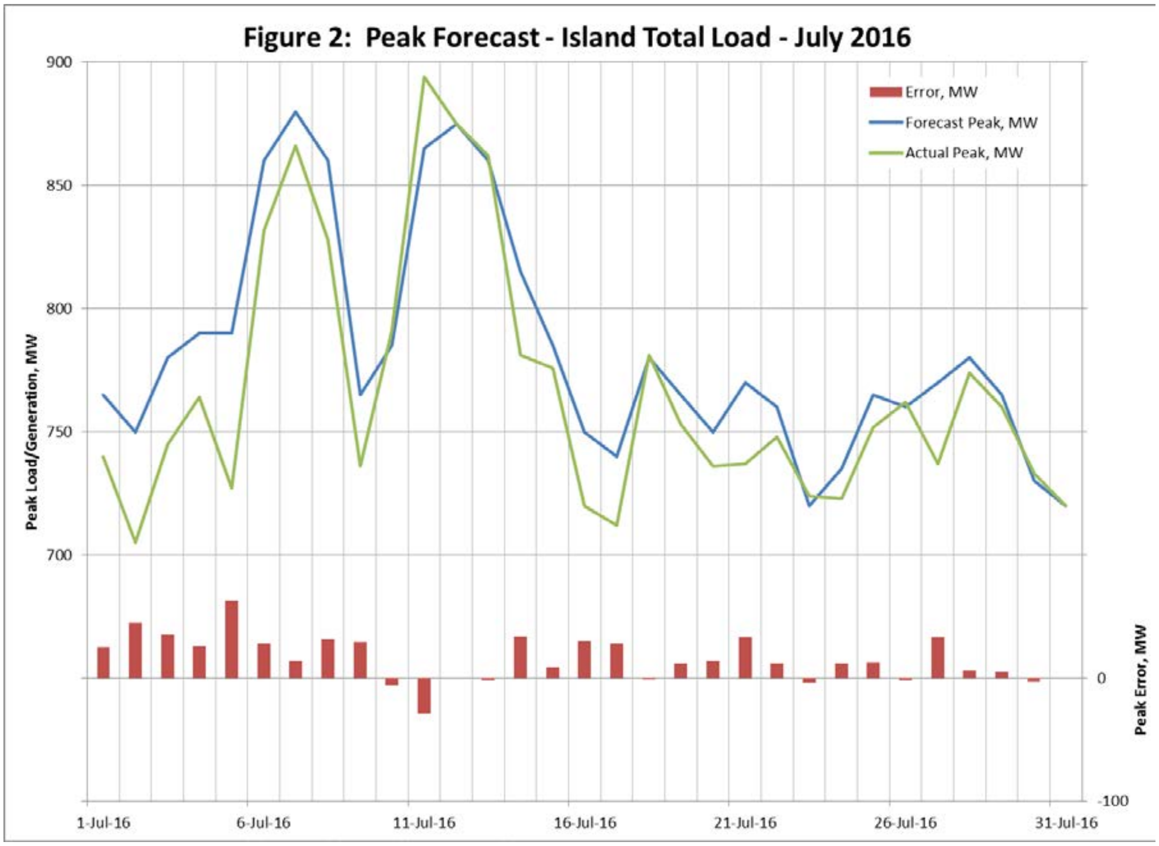


Figure 2: Peak Forecast - Island Total Load - July 2016
Error, MW
Forecast Peak, MW
Actual Peak, MW
Peak Load/Generation, MW
Peak Error, MW
900
850
800
750
700
0
-100
1-Jul-16
6-Jul-16
11-Jul-16
16-Jul-16
21-Jul-16
26-Jul-16
31-Jul-16

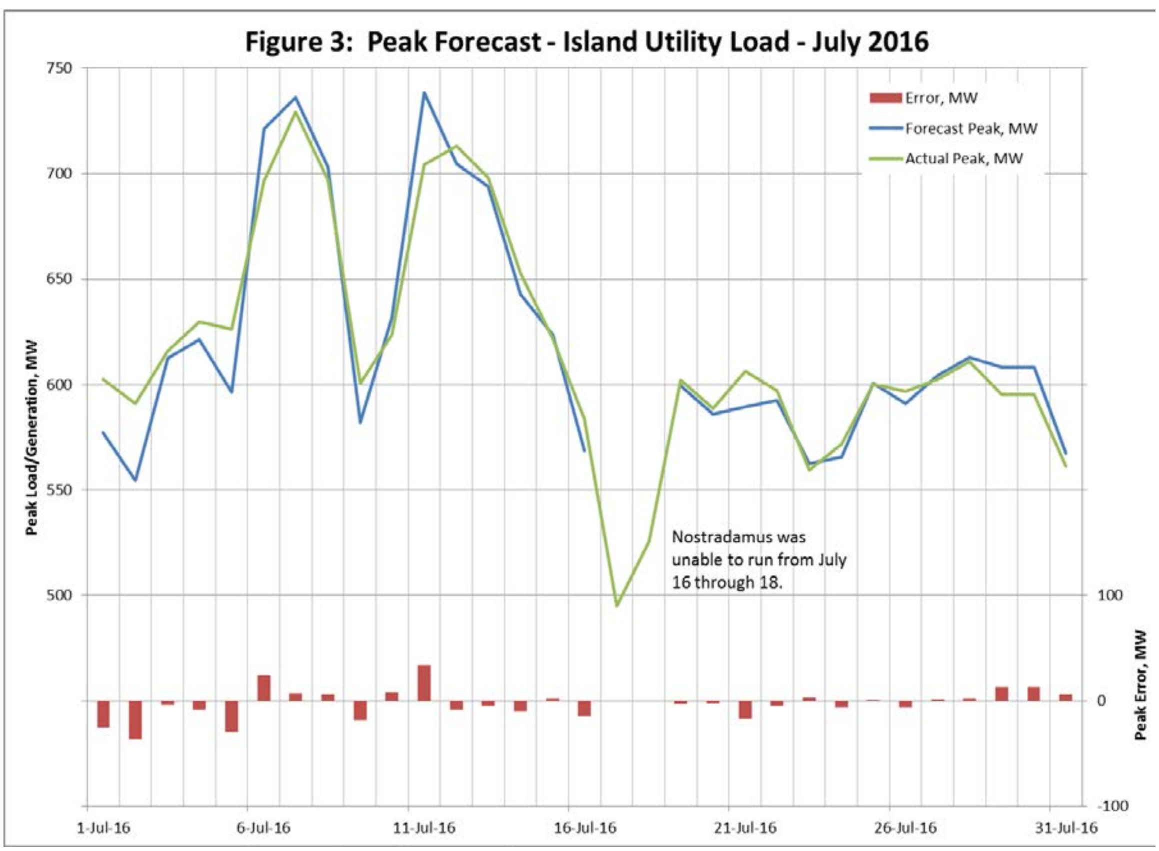


Figure 3: Peak Forecast - Island Utility Load - July 2016
Error, MW
Forecast Peak, MW
Actual Peak, MW
Peak Load/Generation, MW
Peak Error, MW
Nostradamus was unable to run from July 16 through 18.
750
700
650
600
550
500
100
0
-100
1-Jul-16
6-Jul-16
11-Jul-16
16-Jul-16
21-Jul-16
26-Jul-16
31-Jul-16

2.2 Server Issue

On the morning of Saturday, July 16 a server issue prevented Nostradamus from producing updated forecasts for the rest of the weekend. Energy Control Centre operators successfully managed generation and reserves through the weekend without the updated forecasts. When Hydro's Energy Systems staff restarted the server on Monday, July 18, Nostradamus resumed operation. All observation data from the period when the model was out of service was automatically downloaded when the program restarted and was available for use.

2.3 Data Adjustment

On July 29 the RTU at Western Avalon was offline for part of the afternoon, which resulted in incorrect calculation of the Avalon utility load. System Operations replaced the erroneous values in Nostradamus for those three hours by interpolation. These adjustments were made to the Nostradamus data so that in the future, when July 2016 data are used in training the forecasting model, Nostradamus will use a value that is not affected by the data issue.

2.4 July 2, 2015

On July 2, 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 July 2 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 load for the full 24-hour period. The hourly forecast predicted a noon peak of 752 MW; the peak was at 1:00 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 actual load for most of the day; July 2 being one of the days when the Kruger load was lower than forecast by up to 35 MW. The error in the utility forecast in the late morning and at the time of the peak was still high.

Figure 4(c) shows the actual temperature in St. John's compared to the forecast. From 7:00 am till 1:00 pm the forecast underestimated the temperature which could explain some of the error in the load forecast.

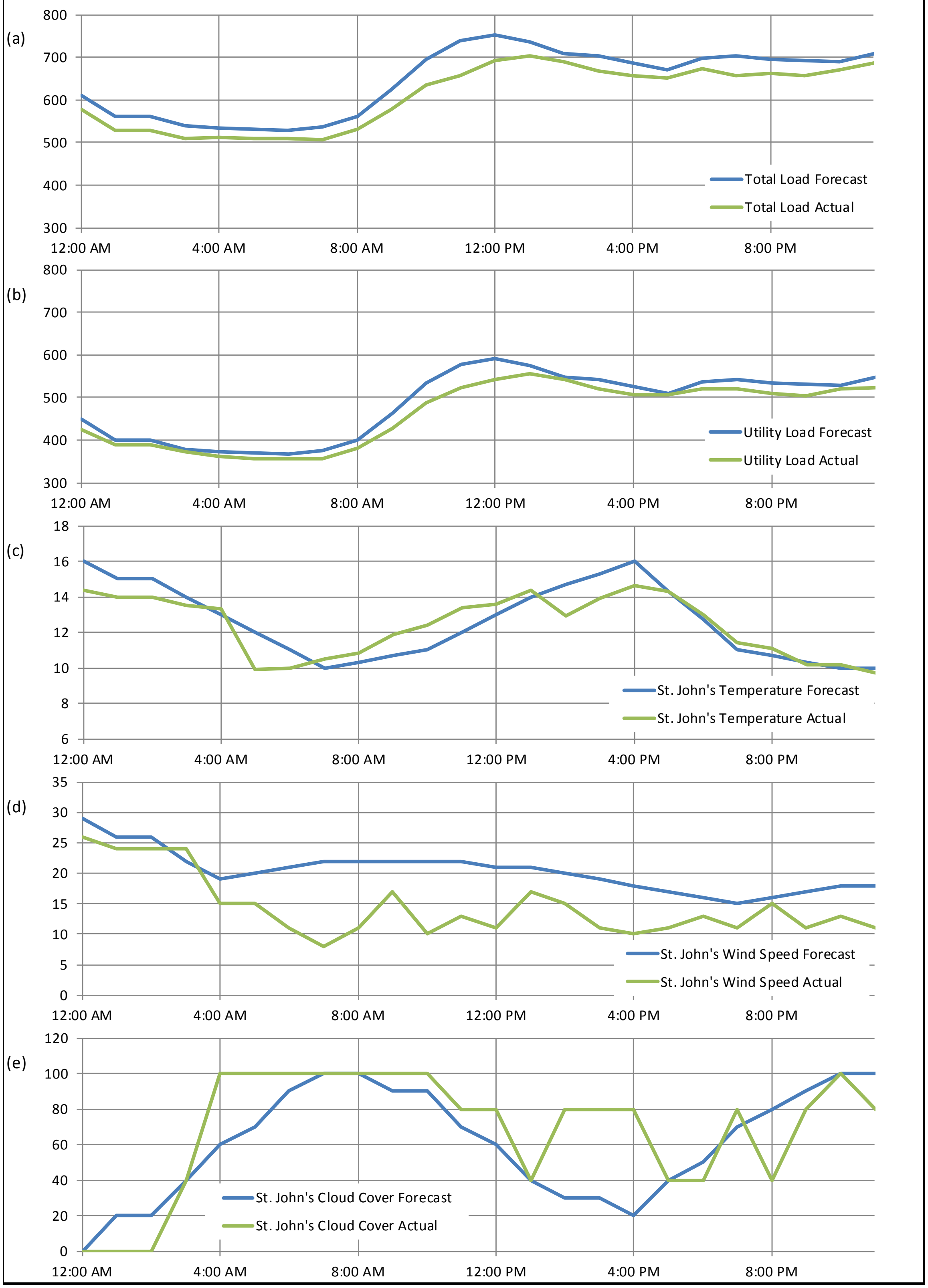
The relationship between load and temperature is harder to predict during the summer. Up to a certain temperature load would continue to drop as heating load reduces but as temperature continues to rise, air conditioning load could become a factor. At 10 to 15 degree temperatures in July, some customers may turn on their heat, others would not. On July 2, the maximum temperature was only 15 degrees so there was likely no air conditioning load, but there may have still been some heating load.

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 again could 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 discrepancy between actual and forecast utility load for July 2 was likely a result of inaccuracies in the temperature and wind speed forecast and perhaps some other factors not modelled by Nostradamus. An overestimate of the load results in more than enough reserve being available.

Figure 4 Accuracy Analysis - Jul 02, 2016



2.5 July 5, 2015

On July 5, the forecast peak at 7:20 am, as reported to the Board, was 790 MW; the actual reported peak was 727 MW. The absolute difference was 63 MW, 8.7% 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 1:00 pm peak of 789 MW, the actual peak occurred at 1:00 pm but was only 724 MW.

Figure 5(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 actual load for most of the day; July 5 being another of the days when the Kruger load was lower than forecast by up to 50 MW. The error in the peak of the utility forecast was only 4.8%.

Figure 5(c) shows the actual temperature in St. John's compared to the forecast. From 7:00 am till 5:00 pm the forecast underestimated the temperature by up to 3 or 4 degrees Celsius. The temperature was forecast to be between 12 and 20 degrees Celsius but was actually between 12 and 22 degrees Celsius. There could have been some heating load at 12 degrees, but at close to 20 degrees at the time of the peak, it should not have been a factor. Air conditioning load would likely not be high at 20 degrees.

Figure 5(d) shows the actual wind speed in St. John's compared to the forecast. At the time of the peak the wind forecast was quite accurate. Figure 5(e) shows the actual cloud cover in St. John's compared to the forecast. The weather was less cloudy than forecast.

The discrepancy between actual and forecast utility load for July 5 may have been partly a result of inaccuracies in the temperature and cloud cover forecasts but was also likely related to other factors not modelled by Nostradamus. An overestimate of the load results in more than enough reserve being available.

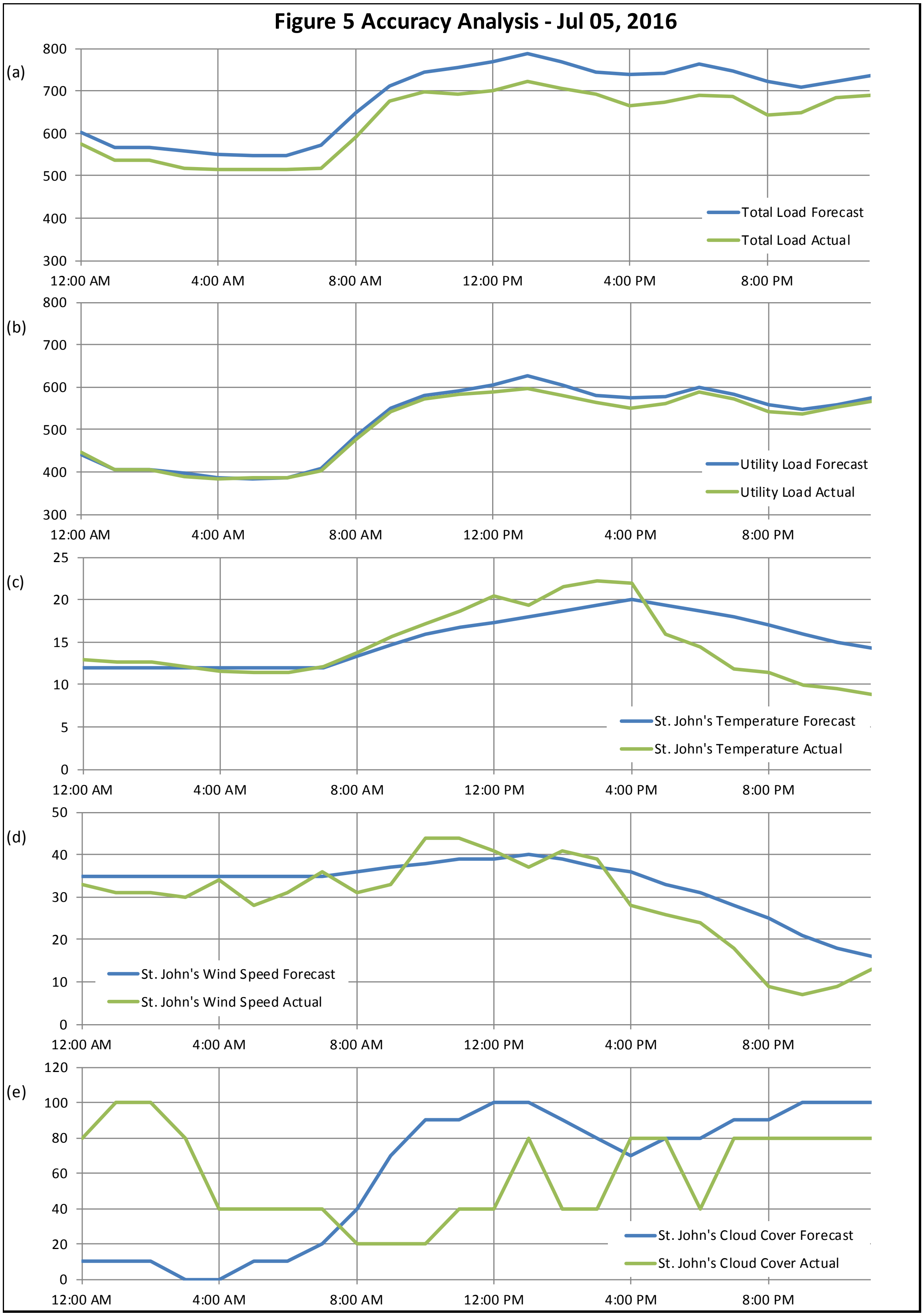


Figure 5 Accuracy Analysis - Jul 05, 2016
(a)
800
700
600
500
400
300
12:00 AM
4:00 AM
8:00 AM
12:00 PM
4:00 PM
8:00 PM
Total Load Forecast
Total Load Actual
(b)
Utility Load Forecast
Utility Load Actual
(c)
25
20
15
10
5
0
St. John's Temperature Forecast
St. John's Temperature Actual
(d)
50
40
30
St. 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