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June 6, 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: May 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: May 2016

Newfoundland and Labrador Hydro

June 2, 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 MAY 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 May 2016. The data are also presented in Figure 1. The actual peaks, as reported to the Board, varied from 800 MW on May 25 to 1160 MW on May 13.

The available capacity during the month was between 1350 MW on May 26 and 1615 MW on May 8. Reserves were sufficient throughout the period.

Table 2 presents error statistics for the peak forecasts during the month of May 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 May the forecast peak was in a range between 3.2% below the actual peak and 11.4% 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 95 MW too high. On average, the forecast peak was 19 MW different than the actual peak, or 2.0%.

The CBPP load was closer to the forecast for May than it had been for the previous several months. The average hourly load was 99 MW, compared to the forecast of 107

MW. This means the industrial portion of the load forecast was more accurate and did not contribute as much to the overall forecast error as in previous months.

This report will further examine the forecast for May 22 when the forecast overestimated the peak by 95 MW or 11.4%, and May 26 when the forecast overestimated the peak by 52 MW, or by 5.6%.

Table 1 May 2016 Load Forecasting Data

Date	Forecast Peak, MW	Actual Peak, MW	Available Island Supply, MW	Forecast Reserve, MW
1-May-16	1040	1012	1580	540
2-May-16	1095	1065	1585	490
3-May-16	1115	1105	1560	445
4-May-16	1100	1116	1555	455
5-May-16	1085	1107	1570	485
6-May-16	1125	1150	1580	455
7-May-16	930	939	1465	535
8-May-16	850	872	1615	765
9-May-16	885	873	1590	705
10-May-16	990	984	1590	600
11-May-16	1060	1042	1575	515
12-May-16	1095	1079	1570	475
13-May-16	1160	1160	1595	435
14-May-16	1010	1004	1580	570
15-May-16	940	900	1570	630
16-May-16	1015	1012	1550	535
17-May-16	1025	1013	1570	545
18-May-16	1035	1025	1585	550
19-May-16	965	941	1535	570
20-May-16	860	849	1465	605
21-May-16	810	804	1470	660
22-May-16	930	835	1475	545
23-May-16	855	835	1475	620
24-May-16	815	820	1470	655
25-May-16	820	800	1490	670
26-May-16	985	933	1350	365
27-May-16	1010	996	1425	415
28-May-16	1005	1038	1410	405
29-May-16	1020	1035	1365	345
30-May-16	970	965	1475	505
31-May-16	960	965	1460	500
Minimum	810	800	1350	345
Average	984	977	1521	535
Maximum	1160	1160	1615	765

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

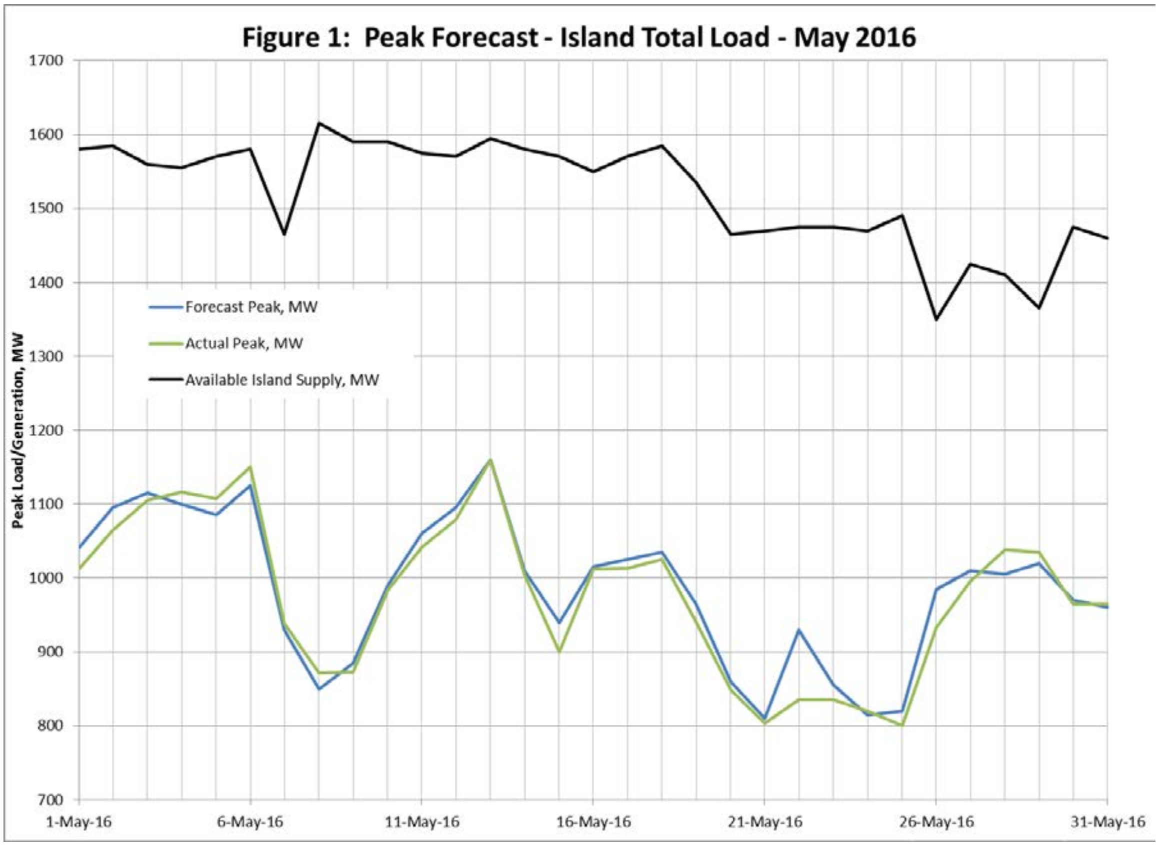
Figure 1: Peak Forecast - Island Total Load - May 2016
Peak Load/Generation, MW
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
Forecast Peak, MW
Actual Peak, MW
Available Island Supply, MW
1-May-16
6-May-16
11-May-16
16-May-16
21-May-16
26-May-16
31-May-16

Table 2 May 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-May-16	1012	1040	28	28	2.8%	2.8%	2.7%
2-May-16	1065	1095	30	30	2.8%	2.8%	2.7%
3-May-16	1105	1115	10	10	0.9%	0.9%	0.9%
4-May-16	1116	1100	-16	16	-1.4%	1.4%	-1.5%
5-May-16	1107	1085	-22	22	-2.0%	2.0%	-2.0%
6-May-16	1150	1125	-25	25	-2.2%	2.2%	-2.2%
7-May-16	939	930	-9	9	-1.0%	1.0%	-1.0%
8-May-16	872	850	-22	22	-2.5%	2.5%	-2.6%
9-May-16	873	885	12	12	1.4%	1.4%	1.4%
10-May-16	984	990	6	6	0.6%	0.6%	0.6%
11-May-16	1042	1060	18	18	1.7%	1.7%	1.7%
12-May-16	1079	1095	16	16	1.5%	1.5%	1.5%
13-May-16	1160	1160	0	0	0.0%	0.0%	0.0%
14-May-16	1004	1010	6	6	0.6%	0.6%	0.6%
15-May-16	900	940	40	40	4.4%	4.4%	4.3%
16-May-16	1012	1015	3	3	0.3%	0.3%	0.3%
17-May-16	1013	1025	12	12	1.2%	1.2%	1.2%
18-May-16	1025	1035	10	10	1.0%	1.0%	1.0%
19-May-16	941	965	24	24	2.6%	2.6%	2.5%
20-May-16	849	860	11	11	1.3%	1.3%	1.3%
21-May-16	804	810	6	6	0.7%	0.7%	0.7%
22-May-16	835	930	95	95	11.4%	11.4%	10.2%
23-May-16	835	855	20	20	2.4%	2.4%	2.3%
24-May-16	820	815	-5	5	-0.6%	0.6%	-0.6%
25-May-16	800	820	20	20	2.5%	2.5%	2.4%
26-May-16	933	985	52	52	5.6%	5.6%	5.3%
27-May-16	996	1010	14	14	1.4%	1.4%	1.4%
28-May-16	1038	1005	-33	33	-3.2%	3.2%	-3.3%
29-May-16	1035	1020	-15	15	-1.4%	1.4%	-1.5%
30-May-16	965	970	5	5	0.5%	0.5%	0.5%
31-May-16	965	960	-5	5	-0.5%	0.5%	-0.5%
Minimum	800	810	-33	0	-3.2%	0.0%	-3.3%
Average	977	984	9	19	1.1%	2.0%	1.0%
Maximum	1160	1160	95	95	11.4%	11.4%	10.2%

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.

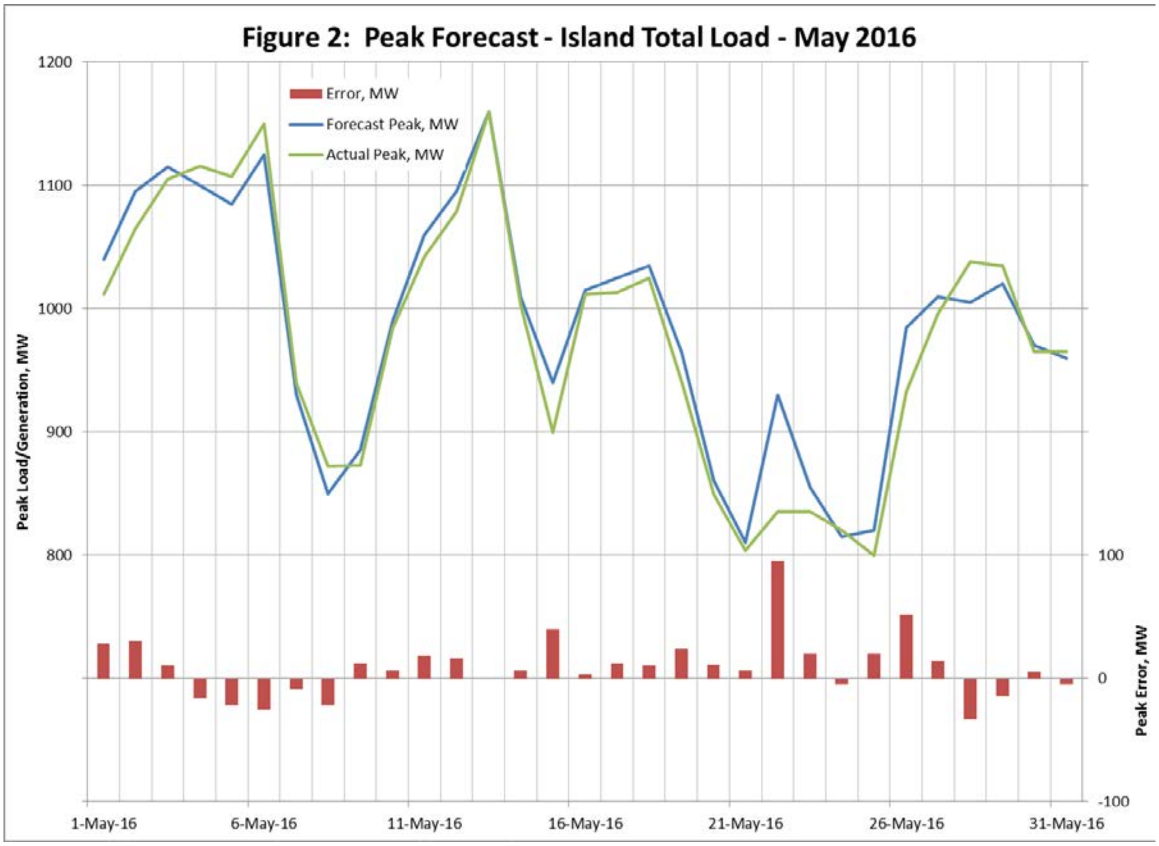

Figure 2: Peak Forecast - Island Total Load - May 2016

2.2 Data Adjustment

On May 5 there was a brief problem with the PI data base that resulted in one hour of incorrect load data being imported into Nostradamus. The data point was corrected shortly after it was input by replacement of the incorrect data with the forecast value. The adjustment is made to the Nostradamus data so that in the future, when May 2016 data are used in training the forecasting model, Nostradamus will use a value that is not affected by the data error.

2.3 May 22, 2015

On May 22, the forecast peak at 7:20 am, as reported to the Board, was 930 MW; the actual reported peak was 835 MW. The absolute difference was 95 MW, 11.4% of the actual. Figure 3 includes an hourly plot of the load forecast for May 22 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 forecast overestimated the load for the full 24-hour period. The forecast predicted a midday peak of 929 MW, but the actual peak was late in the evening, at 10:00 pm and was only 827 MW.

Figure 3(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 actual in the early morning hours but was similar in error to the total forecast for the rest of the day, so error in the industrial portion of the forecast does not explain the forecast error.

Figure 3(c) shows the actual temperature in St. John's compared to the forecast. In the early morning the temperature was overestimated, but for most of the day the temperature was underestimated by up to three degrees. Since temperature has such a significant effect on the heating loads in the province, the error in the temperature likely explains much of the error in the load forecast.

Figure 3(d) shows the actual wind speed in St. John's compared to the forecast. For the first half of the day the actual wind speed was lower than predicted, but at the time of the peak the wind speed was higher than forecast. High winds generally increase the heating load so the error in the wind speed forecast did not contribute to the over forecast of the peak.

Figure 3(e) shows the actual cloud cover in St. John's compared to the forecast. The weather was generally less cloudy than forecast for most of the day, so errors in the cloud cover forecast may have contributed somewhat to the variance in the load forecast.

The discrepancy between actual and forecast load for May 22 was likely primarily as a result of inaccuracies in the temperature forecast. The hourly within-day updates are used by Energy Control Centre operators to manage spinning reserve. An overestimate of the peak results in more than enough spinning reserve.

2.4 May 26, 2015

On May 26, the forecast peak at 7:20 am, as reported to the Board, was 985 MW; the actual reported peak was 933 MW. The absolute difference was 52 MW, 5.6% of the actual. Figure 4 includes an hourly plot of the load forecast for May 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 load for most of the day, but most significantly in the afternoon and evening. The forecast accurately predicted that the peak would occur late in the day, at 10:00 pm, but overestimated the value of the peak.

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 accurate until approximately 2:00 pm, and was somewhat closer to actual utility forecast for the rest of the day so error in the industrial portion of the forecast contributed somewhat to the forecast error.

Figure 4(c) shows the actual temperature in St. John's compared to the forecast. The temperature was underestimated for the middle part of the day; at midday the temperature was up to seven degrees colder than forecast. At the time of the peak however, the actual temperature was very close to forecast. The temperature trend was unusual on May 26 with the temperature at 1:00 am close to 14 degrees, but dropping all day to end at 11:00 pm close to three degrees. Nostradamus tends to be less accurate on days with unusual temperature trends, due to the relatively fewer days in the database to use in developing the relationships.

Figure 4(d) shows the actual wind speed in St. John's compared to the forecast. The error in the wind speed forecast was similar to that in of the temperature forecast, but in this can an overestimate of the wind speed tends to lead to an overestimate of the load. The errors in the temperature and winds speed forecasts likely counteracted each other for some of the day. At the time of the peak the wind speed was less than forecast which likely contributed somewhat to the error in the load forecast.

Figure 4(e) shows that the actual cloud cover in St. John's was as forecast for the full day, so the cloud cover forecast did not contribute to the variance in the load forecast.

The discrepancy between actual and forecast load for May 26 was likely primarily as a result of the unusual trend in the temperature throughout the day and to the error in the wind speed forecast. The hourly within-day updates are used by Energy Control Centre operators to manage spinning reserve. An overestimate of the peak results in more than enough spinning reserve.

Figure 3 Accuracy Analysis - May 22, 2016

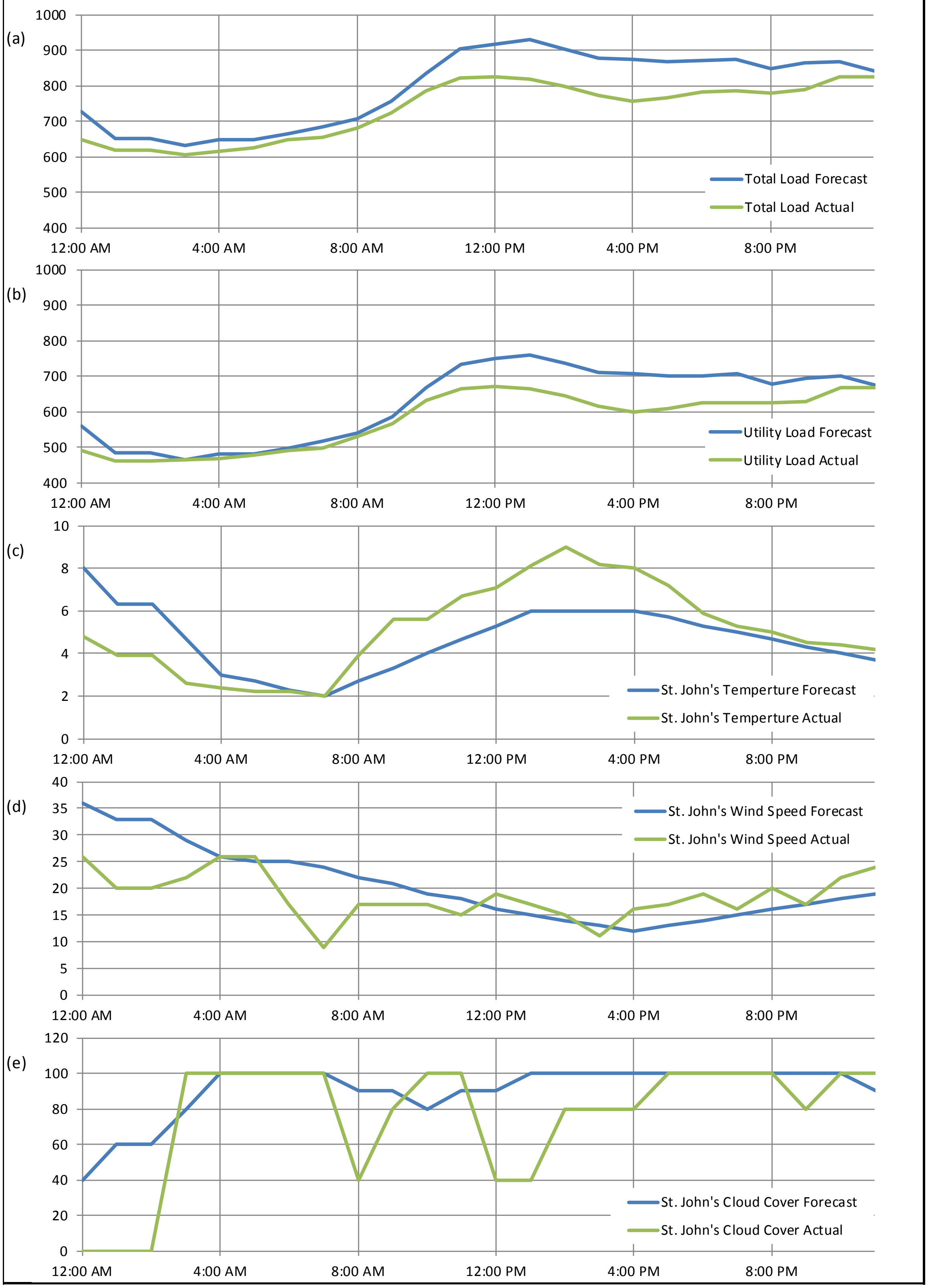

Figure 4 Accuracy Analysis - May 26, 2016