Evaluation of the Impact of Intra-Day and Extended PV and Wind Generation Forecasts on Decision-making in the Planning and Operations of the Jamaica Public Service Grid System

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***Abstract*— A study is in progress to address the issue of which aspects of forecast performance are most critical to providing value for the management of renewable generation variability on an island system with no interconnections and a high penetration of variable renewable generation. Its objective is to identify which forecast information provides the value to operational decision-making and to design a customized forecast evaluation metric that more effectively measures the sensitivity of the operational decision-making environment to forecast error than traditional error metrics.**

The platform for this study is the island grid system operated by Jamaica Public Service (JPS). The system currently has a moderately high penetration of renewable generation with approximately 100 MW of wind-based generation and 20 MW of utility-scale solar-based generation on a system whose net load ranged from 372 MW to 655 MW during 2018.

In addition to other tools, forecasting is being used to assist in the management of the impact of wind and solar variability on the grid system. Traditional forecast error metrics such as MAE or RMSE have been employed but these metrics weight all forecasts equally, and most of the forecast value is concentrated in forecasts made in critical scenarios. A customized forecast evaluation system is being built from (1) the identification of the critical time periods and scenarios as well as the key parameters that impact operational decisions at those times, and (2) the formulation forecast evaluation metrics that emphasizes the performance for the prediction of key parameters during the critical time periods and scenarios.

The initial phase of this project has identified four key daily time periods with characteristic operating issues. A categorical forecast structure has been developed to focus on the key information for each of the decision-making periods. Two metrics have been defined to evaluate the categorical forecasts in a way that emphasizes performance in infrequent but key scenarios.

Keywords-renewable energy forecast value; grid management with high renewable pentration; wind and solar integration

I. Introduction

The increasing penetration level of non-dispatchable variable renewable generation resources such as wind-based and solar-based generators on grid systems have created the need for tools and approaches to assist grid operators in the management of the variability in order to maintain the supply-demand balance and reliability in an economical manner. The need increases as higher amounts of variable resources increases offline cycling of conventional units, unit commitment decisions, and uncertainty in the management of energy resources. In addition to online reserves (which have cost implications), there are a number of flexible energy resources helpful to grid operators managing variability including: (1) energy storage, (2) demand response, (3) active power control of variable generation resources, and (4) flexible, quick-start generation resources. Short-term forecasting of renewable generation variability provides useful insights into the best use of these energy resources to meet reliability and cost goals through more optimized use of the available energy resources. Some of these resources are not available on specific grid systems, due to the limitations of the current mix of system resources and the high cost or lengthy time to make changes to system assets. Short-term forecasting typically has a low implementation barrier and a very favorable cost/benefit ratio. However, the simple availability of forecast data to the grid operator does not guarantee that the potential value of that information will be realized in the grid management process. A key to realizing value from forecast information is the extraction of components that address specific operational issues and inform associated decision-making. It is critical to evaluate and quantify how well the forecast information addresses key operational issues, to instill confidence in the forecast users.

Island grid systems with high variable penetration often have the most acute need for tools to manage the impact of variable generation because of their (1) small system size and therefore high sensitivity to variations in load and generation, and (2) lack of interconnections to buffer supply-demand imbalances. Thus, they are an excellent venue to develop and evaluate methods to optimize the value of forecast information in operational decision-making.

This study addresses the issue of which aspects of intra-day forecast performance are most critical to providing value to the management of the impact of renewable generation variability on an island system with a high penetration of variable renewable generation. The objective is to identify which forecast information provides the value to operational decision-making and to design a customized forecast evaluation metric that more effectively measures the sensitivity of the operational decision-making to forecast error than traditional error metrics.

The venue for this investigation is the island electric system is operated by Jamaica Public Service (JPS).

II. THE OPERATING ENVIRONMENT

The JPS system serves the 2.8 million residents of the Caribbean island of Jamaica. The system-wide net load profile for 2018 is depicted in Figure 1. The "net load" is the measurable demand served by the JPS generation resources and incorporates the "behind the meter" (BTM) PV generation that offsets some of the actual load during the daylight hours. There is some uncertainty about the amount of BTM solar production that is currently on the system but it is small and generally within the "noise" range of the demand variability. Therefore the variability of BTM solar production is not an operating issue at the present time.

The black line in Figure 1 depicts the 2018 average net load for each 30-minute period during the day. The average minimum net load is approximately 450 MW at 3:30 AM. The average peak load is slightly below 600 MW at 7:00 PM. The average mid-day net load is slightly above 500 MW from 8:00 AM to 4:00 PM. The profile of the average net load presents no evidence of a mid-day minimum that usually occurs on systems with a significant about of BTM solar generation

The 2018 maximum and minimum net load for each 30-minute period during the daily cycle is depicted by the dashed red and yellow lines. The minimum net load represented by the dashed yellow line provides a good indication of the demand profile on weekends and holidays. This provides an indication of the range of the net load variability by time of day. The absolute minimum net load was approximately 372 MW and occurred at about 3:00 AM. The 2018 maximum net load was about 655 MW and occurred during the evening peak. The chart indicates that while average mid-day net load is slightly above 500 MW it can range from approximately 425 MW to slightly over 600 MW. Thus, the range during the year is roughly 85 MW (15% to 20% of the average) above and below the average for the 30-minute intervals during the middle of the day. The range in absolute or percentage terms is somewhat less at other times of the day. For example, during the evening peak period the range during the year is from about 510 MW to about 650 MW, which represents a range of about 70 MW above and below the average of about 580 MW at this time of day.

An overview of the generation resources that serve the net load is presented in Tables I and II. Table I summarizes the firm generation capacity on the system. This consists of 46 generation facilities with a capacity of 902.76 MW. As indicated in the table, almost all of this generation capacity is associated with four generation stations. A large portion of this generation is owned and operated by JPS. However, there are several private producers that supply a significant amount of generation capacity. These are specified in the notes below the table.

A very large portion of the electric production on the island is oil-based, with most of it being in the form of diesel generators. There is a small amount of hydro generation. The hydro generation capacity is approximately 29 MW and is obtained from 8 "run-of-river" hydro facilities that are included in the "other" row of Table I and listed in the lower left box of Figure 2.

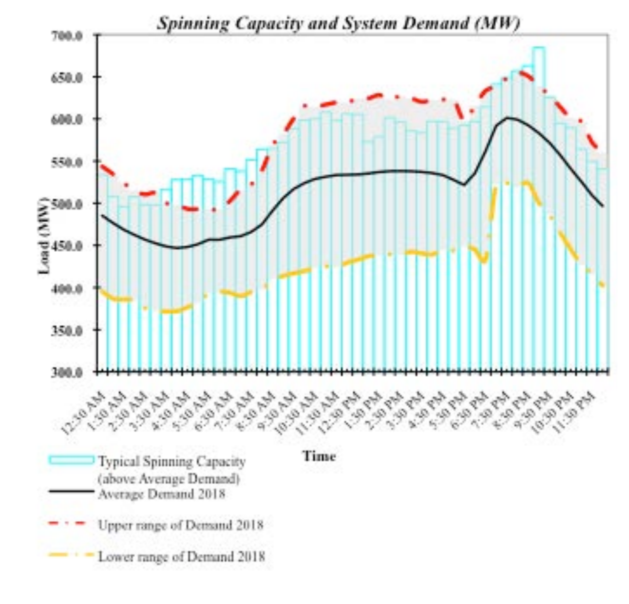

Figure 1. Daily average (black), minimum (yellow) and maximum (red) net load and typical spinning capacity (blue columns) on the JPS system by hour of the day for 2018.

TABLE I. NUMBER OF FIRM GENERATION UNITS AND ASSOCIATED CAPACITY ON THE JPS SYSTEM

Station	Steam	Diesel	GT	Hydro	CC	Cogen	Total	MW
Bogue			6		1		7	225.5
Old Harbour	4	11*					15	347.9
Hunts Bay	1	6***	2				9	188.0
Rockfort		4**					4	101.3
Other				10		1#	11	40.1
Total	5	21	8	10	1	1	46	902.8

NOTES:

* One 124.36MW private producer (JEP) comprising one barge with eight medium speed diesel units at 9.27MW each and another barge with three units of 16.73MW each.
** Consists of a 61.3 MW private producer (JPPC) plant comprising of two (2) slow speed diesel units.
*** One 65.5 MW private producer (WKPP) plant comprising of six (6) medium speed diesel units of 10.92MW each
# 11 MW Bauxite co-generator (Jamalco) contracted. Currently only delivers less than 1 MW

The wind and solar generation facilities on the JPS system are listed in Table II. There are 5 wind generation facilities with a total capacity of 101.3 MW. Currently, there is only one solar generation facility and it has a capacity of 20 MW. However, a second solar generation facility with a capacity of 37 MW is expected to be placed online during the middle of 2019.

All of the generation facility locations are shown in Figure 2. The wind generation capacity and the 20 MW solar facility are located in the south central part of the island. The precise locations of these renewable generation facilities are depicted in Figure 8.

TABLE II. WIND AND SOLAR GENERATION FACILITIES ON THE JPS SYSTEM

Facility	Type	Capacity (MW)
Wigton I	Wind	20
Wigton II	Wind	18
Wigton III	Wind	24
JPS Munro	Wind	3
BMR	Wind	36.3
Total Wind		101.3
Content Solar	Solar	20
Total Solar		20

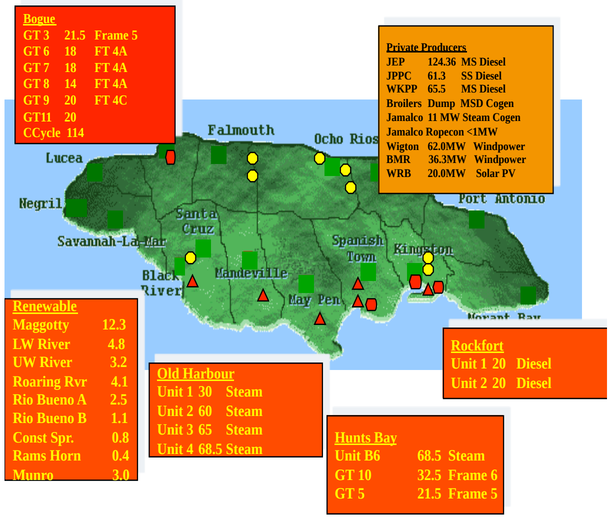

Figure 2. Locations and capacities of the generation resources on the JPS systems in 2018.

There are no interconnections between the JPS grids and any other grid system. Therefore, the JPS system operates without the ability to export or import power from neighboring systems, which of course increases the difficulty in managing generation or demand variability. All balancing must be done by the resources available on the JPS system. Any imbalance results in a system frequency excursion.

III. KEY FORECAST-RELATED OPERATING ISSUES

The shapes of the net load profiles, along with the potential for significant short-term variability of the solar-based and wind-based generation and the attributes of the non-renewable generation resources, combine to create a set of ongoing operating issues that are characteristic of specific times of the day and grid operation scenarios. This section presents on overview of four key decision-making scenarios in which reliable wind and/or solar forecast information have the potential to provide substantial value. However, the critical forecast attributes are different for each scenario.

A. *Unit Commitment for Peak Demand Period*

A potentially significant application of wind and solar forecasts in JPS operations is for short-term unit commitment. A particularly important time period is during the evening system demand peak, which as seen in Figure 1 is typically during the 5 to 9 PM time window. Obviously, solar generation is not a factor during this time of the day. Therefore, the main factor is the expected level of wind generation during this period.

An example of the potential impact of wind forecasts on unit commitment decisions is provided by the June 11, 2018 case. The system demand and system-wide wind generation for this case is shown in Figure 3. The total wind generation was between 40-90 MW during the evening peak period. A gas turbine, with capacity of 14 MW, was committed between the hours of 5:00 and 9:00 PM to assist with the supply during the peak demand period and as a result the system spinning reserve was between 39.6-89.8 MW. If a reliable renewable forecast was available for this day, the decision could have been made to keep the gas turbine offline thus maintaining the system spinning reserve in that period between 25.6-75.8 MW and thus reducing the production cost for peak generation

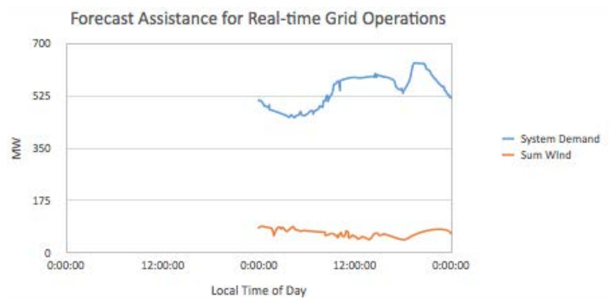

Figure 3. System demand and system-wide wind generation for the June 11, 2018 case

B. *Mid-day Spinning Reserve Management*

Another important decision-making time frame is the mid-day period during which both solar and wind generation variability can pose significant issues for system management. The primary issue at this time is the optimization of the spinning reserve. The critical forecast parameter at this time is the range of the solar and wind production

The April 15, 2018 case (Figure 4) provides a good example of this type of application of renewable energy forecast information. On that day, wind and solar generation was highly variable and in addition, one of the major responsive units was offline, resulting in frequent operation of the automatic Under Frequency Load Shed (UFLS) scheme. Three other units were carrying reserve but their response was sluggish and one of them actually had its droop control disabled unsuspectedly. Hence, droop response was only offered by two units.

If an accurate forecast of the range of wind and solar generation variability was available for this day steps could have been made to ensure that droop was enabled for all responsive units. Additionally, the decision could have made to bring online the most efficient gas turbine to assist with droop response for mitigation of the wind and solar variability, hence optimizing the spinning reserve and reducing customer interruptions

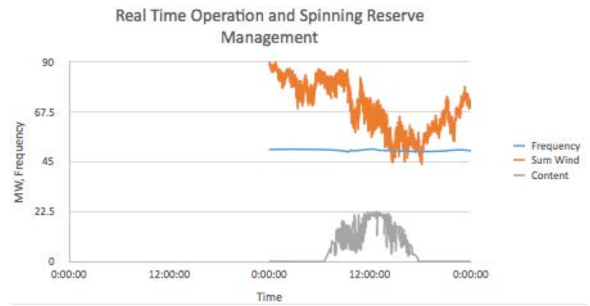

Figure 4. System-wide wind and solar generation and system frequency for April 15, 2018.

C. *Day-ahead Unit Commitment and T&D Outage Planning*

A third type of operating issue that was identified was the day-ahead unit commitment in conjunction with transmission and distribution (T&D) planning.

An example of this type of forecast application occurred on March 11, 2018 (Figure 5). On this day, a T&D outage was executed on transmission assets at a major generation substation. One of two major transmission lines from this substation was also out of service (o/s) between 5:00 AM and 5:00 PM. In addition, a 138kV/69kV interbus transformer from that substation was o/s between 3:00 PM and 5:00 PM. The peak capacity of wind generation is approximately 100 MW. This setup forced the power export from this substation through the one remaining line and the interbus, when it was in service, to a major load center.

Throughout this outage wind generation was consistently above 80 MW. At about 10:00 AM the decision had to be made to curtail wind generation to sustain a maximum peak wind generation of approximately 80 MW. This was to mitigate against losing the same interbus, when it was in service, rated at 37.5 MVA, in the event of the trip of one of the one remaining major 138 kV line from the substation.

If an accurate wind and solar generation forecast was available during the planning of the T&D outage, a decision could have been made to further curtail inefficient thermal units that have long required uptime that are connected to the substation. This would allow the acceptance of maximum output from the wind plants and any generation deficit made up by a more efficient unit at the same substation. This would have possibly reduced production cost while securing the network throughout this T&D outage.

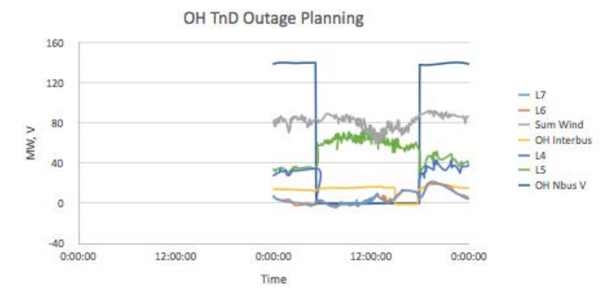

Figure 5. Wind generation and transmission availability at a major JPS generation substation for March 11, 2018.

D. *Planning for Generation Maintenance*

A fourth type of application for wind and solar forecast information is the planning of outages for generation maintenance. The key question is whether there will be a sufficient contingency reserve during the peak demand period (i.e. the evening peak) to accommodate the planned outage. If there is confidence that the wind generation is very likely to be above a threshold level at all times in the peak demand periods during the anticipated maintenance outage period then the wind generation could be included in the calculation of the available contingency reserve. However, without a reliable forecast, the wind generation is not included in the calculation. The typical forecast look-ahead time frame for this application is about 7 days.

An example of this type of application on the JPS system occurred during the period of October 19-23, 2017. The system demand and system-wide wind generation for this period is shown in Figure 6. A generating station had proposed a planned outage for one of their units with a capacity 30 MW for this period. The available generation capacity prior to commencement of that outage was 714.48 MW and the forecasted peak demand was 650 MW, which was later revised to 625 MW. The contingency reserve needed for the granting of planned outages is 80 MW. Hence with the outage of the 30 MW unit the operating reserve for peak system demand would be approximately 59.48 MW, without consideration of variable renewable energy plants. This would be 20.52 MW less than the acceptable limit of 80 MW operating reserve. As a result, the planned outage was cancelled, but the unit was still forced offline.

If there had been an accurate wind forecast for the duration of the planned outage, it could have been determined that the minimum wind generation during the evening peaks would have been 19.9 MW. Hence the deficit in the operating reserve would have been 0.62 MW, a negligible amount, thus the generation maintenance outage could have been granted.

Thus, the key forecast attribute for this application is the skill of predicting the minimum system-wide wind generation during the peak demand period of the daily cycle (5-9 PM).

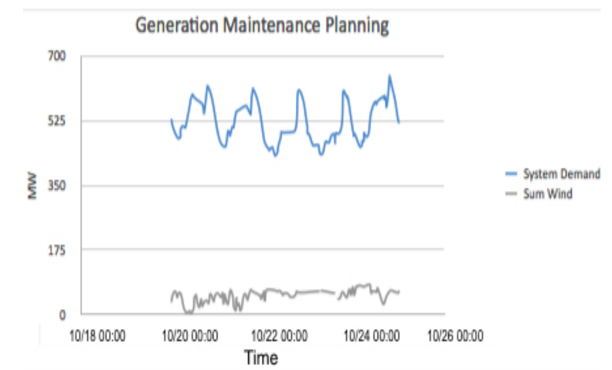

Figure 6. System-wide demand and total wind generation for the period of October 19-23. 2017.

IV. Renewable Generation Forecast System

JPS began receiving wind and solar generation forecasts from two providers during 2018. Since JPS currently has only limited experience with the operational use of renewable energy forecasts, they are still in the early stages of the process of determining how to obtain optimal value from the forecasts and what type of forecast information is most relevant to their operational processes. They expect that the content and format of the forecasts as well as the manner in which they are used will evolve as more experience is accumulated.

One of the forecast providers is AWS Truepower, a UL Company (UL), which provides forecasts from a forecast system that is customized for JPS. Only forecasts from this system are considered in this paper. These forecasts based on the multi-method ensemble approach to forecasting. In this approach, forecasts are generated by multiple forecast algorithms. The ultimate forecast is created by statistically constructing a deterministic or probabilistic composite of the individual forecasts. This is similar to the system employed by UL for the Hawaiian Electric Company [1].

Forecasts from UL are provided on three different look-ahead time scales. The first is a 6-hour look-ahead period with a forecast increment of 5 minutes that is updated every 5 minutes. This forecast mode is targeted for intra-day decision-making. The second look-ahead time frame is the next calendar day. These extend through midnight of the next calendar day. They have a forecast increment of 15 minutes and are updated every 6 hours. The third look-ahead time frame is an extended range period of 14 days. These forecast have a time resolution of 1 hour and are issued once per day at 0600 EST. The forecast content is the same for all look-ahead time periods.

Wind and solar generation forecasts are provided for each utility-scale facility. These are combined to produce separate system-wide wind and solar generation forecasts as well as a combined system-wide wind and solar generation forecast.

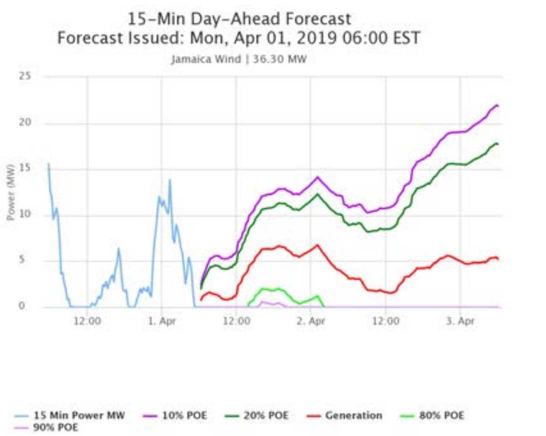

Figure 7. A forecast for wind generation (MW) for a facility on the JPS system that was produced at 0600 HST April 1, 2019. The red line represents the deterministic wind generation forecast. The blue line is the estimated actual generation prior to the forecast issue time. The green and purple lines are the probability of exeedance (POE) forecasts at the 10%,20%, 80% and 90% levels.

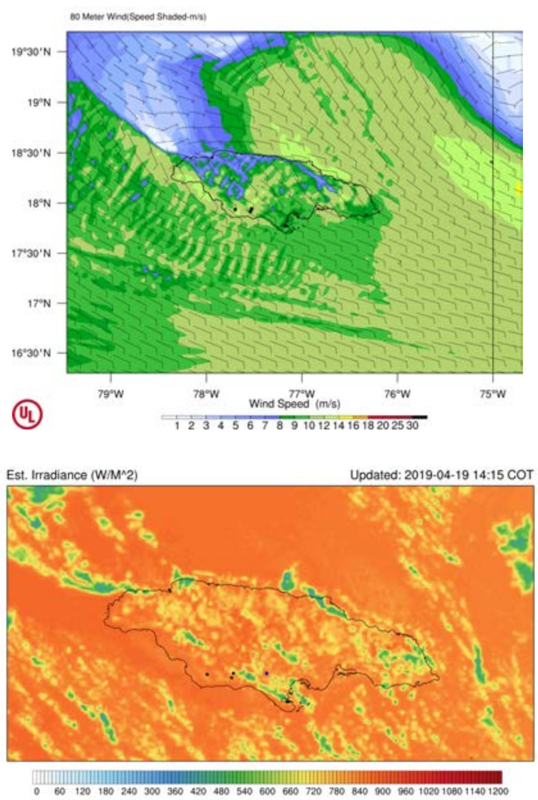

Figure 8. Examples of the maps of the current geographical patterms of (top) 80-m wind and (bottom) Global Horizontal Irradiance (GHI) that are provided to JPS for situational awarness. These are compiled from multiple sensor and NWP model datasets and are updated at 15-minute intervals. The black circle markers in the south central part of the island denote locations of the wind (westernmost three markers) and solar generation (easternmost marker) facilities.

An example of a day-ahead wind forecast is shown in Figure 7. The forecast is expressed in terms of a “deterministic” forecast (red line) and four probability of exceedance (POE) values (green and purple lines). This implicitly provides some information about the probability density function at each look-ahead time.

In addition to the forecast information, UL Renewables provides maps of the current geographical patterns of the wind and solar resources over the JPS service area for situational awareness. Examples of these are shown in Figure 8.

V. CUSTOMIZED METRICS

A set of customized metrics was developed to measure the prediction skill with respect to the forecast attributes that are important to each decision-making scenario. An event-oriented category-based approach was employed. Each decision-making scenario (e.g. planning for the evening demand peak) and decision component (e.g. wind, solar or both) was considered a separate event. The forecasts for each event were expressed in a 3-category structure. The argument for a category-based structure is that decisions are typically based on an interpretation of information that divides the potential scenarios into bins for which the same decision will be made with little consideration of differences within the bins and the bins will have sharp boundaries that define the transition between alternative decisions. From a forecast evaluation perspective this means that the important attribute is the ability to correctly distinguish the outcome category in a structure in which category boundaries are aligned with the transitions between alternative decisions.

The simplest way to visualize this concept to forecast evaluation is through the use of a contingency table of forecasted vs. observed (outcome) categories. A depiction of a 3-category contingency table is shown in Figure 8. This illustrates three forecast categories in the horizontal direction and the corresponding three outcome categories in the vertical direction. Table cells 3, 5 and 7 (shaded in green) represent the correct forecasts. The cells shaded in yellow represent 1-category errors while the cells shaded in red represent 2-category errors.

The distribution of forecasts-outcome pairs among the cells provides an indication of forecast performance. However, it is useful to compress the set of numerical values in the cells into a single performance metric. Two different metrics are being used for this purpose: (a) Critical Success Index (CSI) and (b) General Skill Score (GSS).

Bin #	Forecasted Category			
Onserved Category	Category	F_1: Below	F_2: Typical	F_3:Above
	O_3: Above	1	2	3
	O_2: Typical	4	5	6
	O_1: Below	7	8	9

Figure 8. An example of a forecasted vs observed contingency table with numeric labels (1 to 9) assigned to each table cell.

A. *Critical Success Index (CSI)*

The CSI is a widely used event-oriented forecast performance metric [2] that is defined as

$$CSI = H/(H + M + FA), \qquad (1)$$

where H is number of "hits" (event is forecasted and observed), M is the number of misses (event is observed but not forecasted) and FA is the number of false alarms (event is forecasted but not observed). For example, if "Above" in the contingency table (Figure 8) is defined as an event then H is the number of outcomes in cell #3, M is the sum of the outcomes in cells #1 and #2 and FA is the sum of outcomes in cells #6 and #9. Note that the other cells are not considered since they represent outcomes with neither forecast nor observed events. From this example, it can be seen that the calculation of the CSI depends upon the definition of an "event".

The CSI ranges from 0 to 1 (or 0% to 100%). If all forecasts are hits then M and FA are zero and the CSI is 100%. If no forecasts are hits then the CSI is 0%. While the CSI is simple to calculate and understand it is not a comprehensive nor flexible metric. For example, it is desirable to place greater weight on critical decision-making situations in the evaluation metric

B. *General Skill Score (GSS)*

Many of the issues with the CSI can be addressed through the use of a generalized skill score (GSS) in a manner similar to that formulated by [3] and [4]:

$$GSS = \frac{1}{N}\sum_{i=1}^{K}\sum_{j=1}^{K} n(F_i, O_j)s_{ij} \qquad (2)$$

where N is the total number of forecasts and $n(F_i,O_j)$ is the number of forecasts that fall into the cell identified as foreacst category "i" and observed category "j", K is the number of categories and s_{ij} is a scoring matrix that weights the contribution of each cell ($_{ij}$) to the GSS value.

This metric differs from the CSI metric by considering all forecast-outcome combinations (i.e. all cells in the contingency matrix) and also by the use of a scoring parameter (s_{ij}) that weights the contribution of each matrix cell in the calculation of the overall metric. The scoring metric provides the flexibility for customization. For example, it can be used to account for the sensitivity of the decision-making process to a particular type of error. For example, misses of particular outcomes can be penalized more than false alarms of that outcome but misses and false alarms of other outcomes can be treated equally.

The properties of the GSS will depend upon the specification of the scoring matrix. A widely used definition of the scoring matrix treats all errors equally, has a linear penalty for multiple category errors (e.g. 2 category errors could be penalized twice as much as 1 category errors), requires a score of 1.0 for all correct forecasts, and formulates the scoring matrix values such that a random forecast of the categories (with knowledge of the relative observed frequencies) will produce a GSS value of zero. In that case, if all forecasts are correct the GSS is 1.0 (100%). This is the specification used in this project.

VI. PERFORMANCE EVALUATION RESULTS

Since JPS just initiated the reception and use of wind and solar forecasts during 2018, the development of a customized forecast evaluation and optimization approach based on the category-based methods described in Section V for each of the four types of JPS forecast applications described in Section IV is still in progress. The first step in this process was to establish a baseline by evaluating the forecasts with traditional performance metrics such as the mean absolute error (MAE). While these MAE scores can be compared to those published in the technical literature or presented at conferences, they provide very little information about the value of the forecasts for JPS operational decision-making.

The next step in the process is to define (1) the critical forecast issue and target time frames for each application, (2) the forecast parameter(s) that is most relevant to each decision-making process and (3) the categories (i.e. ranges) of forecast parameter values that are significant for the operational decisions. The subsequent step is to use the category-based structure and these definitions to evaluate the existing forecasts. These forecasts are not optimized for the forecast attributes that were identified for each type of decision. The concluding step is to optimize the forecast production process to achieve optimal performance for the key decision-making parameters.

VII. SUMMARY

A study is in progress to identify which aspects of forecast performance are most critical for the management of renewable generation variability on an island system with no interconnections and a high penetration of variable renewable generation. The initial objective is to identify which forecast information provides the most value to operational decision-making and to then design customized forecast evaluation metrics that more effectively measure the sensitivity of the operational decision-making environment to forecast error than traditional error metrics. The ultimate objective is to optimize the forecast system to achieve the best possible performance as measured by these metrics.

The platform for this study is the island grid system operated by Jamaica Public Service. The system currently has a moderately high penetration of renewable generation with 100 MW of wind-based generation and 20 MW of utility-scale solar-based generation on a system whose net load ranged from 372 MW to 655 MW during 2018. This high penetration of variable renewable resources on a system with no interconnections poses a number of operating issues that have to be addressed to maintain the balance of supply and demand and grid stability.

In addition to other tools, forecasting is being used to assist in the management of the impact of wind and solar variability on the grid system. Traditional forecast error metrics such as MAE or RMSE have been used but these weight all forecasts equally, and most of the forecast value is concentrated in forecasts made at key decision-making times of the day in critical scenarios. A customized forecast evaluation system is being built from (1) the identification of the critical time periods and scenarios as well as the key parameters that impact operational decisions at those times, and (2) the formulation of forecast evaluation metrics that emphasizes the performance for the prediction of key parameters during the critical time periods and scenarios.

The initial phase of this project has identified four key scenarios with characteristic operating issues. A categorical forecast structure has been developed to focus on the key information for each of the decision-making periods. A generalized skill score has been defined to evaluate the categorical forecasts in a way that emphasizes performance in infrequent but key scenarios.

ACKNOWLEDGMENT

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