Alternative Methodology
DRAFT Client Confidential

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1 Estimating Service Need

1.1 Forecast Errors

Forecast errors by definition are derived as:

$$\varepsilon = ACTUAL - FORECAST$$

1.2 Forecasts

As presented in our original methodology, forecasts are to be generated by escalating historical load and drawing from an error distribution. Specifically, the 5-minute forecast, hour-ahead forecast, and day-ahead forecast for load and wind [1] will be calculated in the following way:

$$Load^{5-min\ forecast} = L_5^a - \varepsilon_{5L} \quad (1)$$
$$Load^{HA\ forecast} = L_{60}^a - \varepsilon_{60L} \quad (2)$$
$$Load^{DA\ forecast} = L_{60}^a - \varepsilon_{DL} \quad (3)$$

Where:

$$L_5^a = \text{actual 5-min load} \quad (4)$$
$$L_{60}^a = \text{actual hourly (60-min) load} \quad (5)$$
$$\varepsilon_{5L} = \text{5-min load forecast error} \quad (6)$$
$$\varepsilon_{60L} = \text{hourly (60-min) load forecast error} \quad (7)$$
$$\varepsilon_{DL} = \text{day-ahead load forecast error} \quad (8)$$

$$Wind^{5-min\ forecast} = W_5^a - \varepsilon_{5W} \quad (9)$$
$$Wind^{HA\ forecast} = W_{60}^a - \varepsilon_{60W} \quad (10)$$
$$Wind^{DA\ forecast} = W_{60}^a - \varepsilon_{DW} \quad (11)$$

[1] We will use L to refer to load and W to refer to wind and/or any other intermittent resource on the grid

Where:

$$W_5^a = \text{actual 5-min wind} \quad (12)$$
$$W_{60}^a = \text{actual hourly (60-min) wind} \quad (13)$$
$$\varepsilon_{5W} = \text{5-min wind forecast error} \quad (14)$$
$$\varepsilon_{60W} = \text{hourly (60-min) wind forecast error} \quad (15)$$
$$\varepsilon_{DW} = \text{day-ahead wind forecast error} \quad (16)$$

Actual load is generated by escalating base year (historical load) and actual wind is similarly derived by escalating it to the study year profile. All forecast errors are generated from corresponding normal (and possibly truncated [2]) distributions whose parameters (μ, σ) are adjusted for growth between the base year (e.g. 2006) and the study year (e.g. 2015) [3].

1.3 Alternative Methodology

In the absence of reliable 1-minute and 5-minute data on load and wind (IR) we have to adjust the methodology to the extent to which it relies on such data. Specifically, we need to adjust the methodology for calculating regulation, load-following, and day-ahead scheduling error.

The CAISO report states that, "for each time frame, the forecast error was determined by taking the difference between the forecast demand for that time frame and the actual average demand for the corresponding period" (CAISO 2007 *Integration of Renewable Resources*, p. C-1). This implies that forecast errors only account for the average intra-period variation–the rest of the variation in hourly and seasonal results is driven by the historical shape of the data. Lack of 1-min and 5-min actual and forecast data is likely to affect regulation estimates the most and, hence, we should make appropriate adjustments. For example, with regulation, we are dealing with two levels of variation–variation of the average 1-minute load (calculated over 5 minutes) around the 5-minute forecast and the variation of the actual 1-minute load observations around the 5-minute forecast–see Figure 1.

[2] It might be prudent to avoid truncating the normal distribution if we believe that in practice we often see long tails and, as a result, should be able to plan for periods in which observations will fall into the ends of those long tails of the quasi-normal distribution.

[3] For example, the hour-ahead forecast for load in 2015 will be derived as:

$$Load_{2015}^{HA\,forecast} = Load_{2006} \times (1+\gamma)^{2015-2006} - \varepsilon_{2015}^{HA}$$

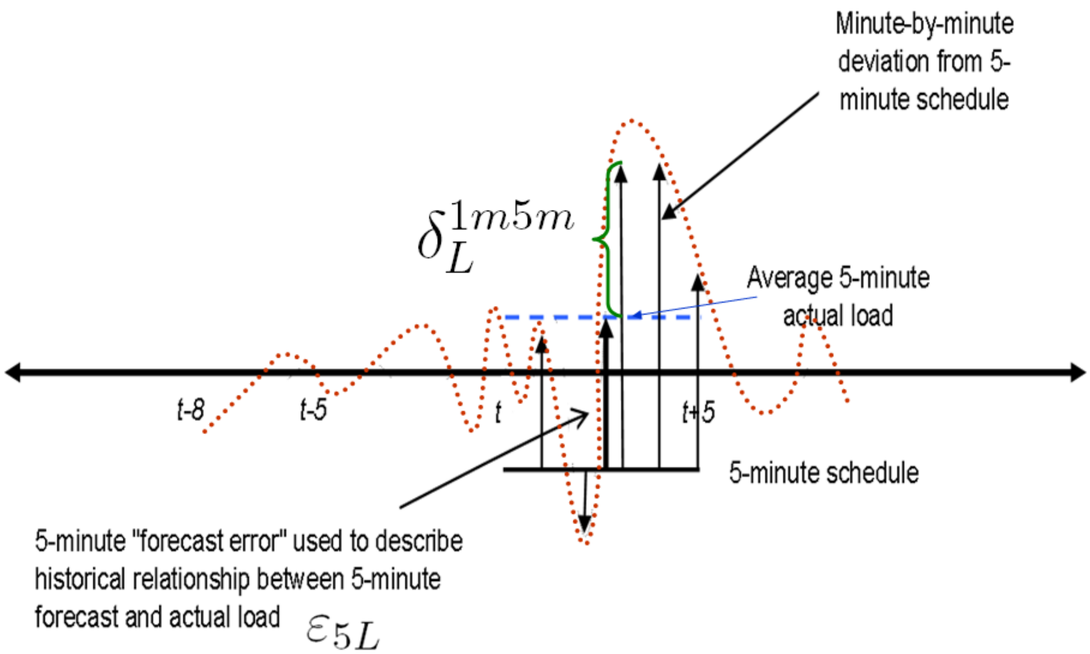

Figure 1: Two Sources of Variability

Using escalated actual 1-minute load/wind and interacting it with a simulated study year forecast allows for capturing both of these dynamics. However, the absence of actual 1-minute data requires that we parameterize the intra-period volatility in some way. The same logic applies to the other services, where such dynamics are present and where we lack relevant period-by-period data.

1.4 Regulation

Ideally, in the presence of reliable 1-minute data, we would use:

$$Regulation_{\text{every 1 min}} = Load^{actual}_{1min} - Load^{5minforecast} + Wind^{5minforecast} - Wind^{actual}_{1min}$$

(assume *Wind* stands for IR in general)

$$= L^a_1 - (L^a_5 - \varepsilon_{5L}) + (W^a_5 - \varepsilon_{5W}) - W^a_1$$

define the difference between the 1-minute actual and the 5 min actual (which is really the average of *five* 1-minute observations) as:

$$\delta^{1m5m}_L = L^a_1 - L^a_5$$

$$\delta^{1m5m}_W = W^a_1 - W^a_5$$

As a result:

$$Regulation = \delta^{1m5m}_L + \varepsilon_{5L} - \delta^{1m5m}_W - \varepsilon_{5W}$$

In order to calculate the variance of this expression, we need to make assumptions about the presence or lack of independence among the four (random) variables. Considering the context, we assume that the 5-minute forecast errors for wind and load are correlated and that, separately for load and wind, the five minute forecast error is correlated with the corresponding intra-5min volatility variable. Therefore, the variance of regulation experession:

$$Var(Regulation) = Var(\delta^{1m5m}_L + \varepsilon_{5L} - \delta^{1m5m}_W - \varepsilon_{5W})$$

will simplify to:

$$Var(Regulation) = Var(\delta^{1m5m}_L) + Var(\varepsilon_{5L}) + Var(\delta^{1m5m}_W) + Var(\varepsilon_{5W}) + \\ + 2Cov(\delta^{1m5m}_L, \varepsilon_{5L}) + 2Cov(\delta^{1m5m}_W, \varepsilon_{5W}) - 2Cov(\varepsilon_{5L}, \varepsilon_{5W}) \quad (17)$$

In the model, we parametrize the known variances and, also, the correlation coefficients (ρ) between the variables in order to calculate the variance of regulation (or any of the other services).

As a result the formula used to calculate the variance of regulation transforms to:

$$\begin{aligned} Var(Regulation) = {} & Var(\delta_L^{1m5m}) + Var(\varepsilon_{5L}) + Var(\delta_W^{1m5m}) + Var(\varepsilon_{5W}) + \\ & + 2\rho_{\delta_L^{1m5m},\varepsilon_{5L}}\sqrt{Var(\delta_L^{1m5m})Var(\varepsilon_{5L})} + \\ & + 2\rho_{\delta_W^{1m5m},\varepsilon_{5W}}\sqrt{Var(\delta_W^{1m5m})Var(\varepsilon_{5W})} - \\ & - 2\rho_{\varepsilon_{5L},\varepsilon_{5W}}\sqrt{Var(\varepsilon_{5L})Var(\varepsilon_{5W})} \end{aligned} \tag{18}$$

This becomes the simulated/parameterized variance of Regulation Service, which can be seasonally generated. The user will provide:

$$\sigma_{\varepsilon_{5L}} = \sqrt{Var(\varepsilon_{5L})} = \text{standard deviation of the 5-min load forecast error} \tag{19}$$

$$\sigma_{\varepsilon_{5W}} = \sqrt{Var(\varepsilon_{5W})} = \text{standard deviation of the 5-min wind forecast error} \tag{20}$$

$$\rho_{\delta_L^{1m5m},\varepsilon_{5L}},\ \rho_{\delta_W^{1m5m},\varepsilon_{5W}},]\ \rho_{\varepsilon_{5L},\varepsilon_{5W}} = \text{user-specified correlation coefficients (between [-1,1])} \tag{21}$$

$$\sigma_{\delta_L^{1m5m}} = \sqrt{Var(\delta_L^{1m5m})} = \text{variance of intra-5-min difference b/w av. 5-min load and 1-min actual load} \tag{22}$$

$$\sigma_{\delta_W^{1m5m}} = \sqrt{Var(\delta_W^{1m5m})} = \text{variance of intra-5-min difference b/w av. 5-min wind and 1-min actual wind} \tag{23}$$

In the implementation of the tool, (20) is actually provided for an option of 4 distinct IR technologies and the tool calculates a composite standard deviation for IR.

1.5 Load-Following

Ideally, in the presence of reliable 5-minute data, we would use:

$$LF_{\text{every 5 min}} = Load^{5minforecast} - Load^{HA\ forecast} + Wind^{HA\ forecast} - Wind^{5minforecast}$$

Similar to our approach in the case of Regulation Service, here we will parametrize the intra-hour volatility of 5-min load (wind):

$$\delta_L^{5m60m} = L_5^a - L_{60}^a$$

$$\delta_W^{5m60m} = W_5^a - W_{60}^a$$

Rearranging, we get:

$$LF = L_5^a - L_{60}^a + \varepsilon_{60L} - \varepsilon_{5L} - (W_5^a - W_{60}^a) + \varepsilon_{5W} - \varepsilon_{60W}$$

Which simplifies to:

$$LF = \delta_L^{5m60m} + \varepsilon_{60L} - \varepsilon_{5L} - \delta_W^{5m60m} + \varepsilon_{5W} - \varepsilon_{60W}$$

Again, we will proceed to calculate the variance by recognizing which elements are independent and which ones have nonzero covariance.

$$Var(LF) = Var(\delta_L^{5m60m} + \varepsilon_{60L} - \varepsilon_{5L} - \delta_W^{5m60m} + \varepsilon_{5W} - \varepsilon_{60W})$$

Therefore, the variance of Load Following service is:

$$\begin{aligned} Var(LF) = {} & Var(\delta_L^{5m60m}) + Var(\varepsilon_{60L}) + Var(\varepsilon_{5L}) + \\ & + Var(\delta_W^{5m60m}) + Var(\varepsilon_{60W}) + Var(\varepsilon_{5W}) + \\ & + 2\rho_{\delta_L^{5m60m},\varepsilon_{60L}} \sqrt{Var(\delta_L^{5m60m}) Var(\varepsilon_{60L})} + \\ & + 2\rho_{\delta_W^{5m60m},\varepsilon_{60W}} \sqrt{Var(\delta_W^{5m60m}) Var(\varepsilon_{60W})} - \\ & - 2\rho_{\varepsilon_{5L},\varepsilon_{5W}} \sqrt{Var(\varepsilon_{5L}) Var(\varepsilon_{5W})} - \\ & - 2\rho_{\varepsilon_{60L},\varepsilon_{60W}} \sqrt{Var(\varepsilon_{60L}) Var(\varepsilon_{60W})} \end{aligned} \quad (24)$$

The above result is based on the following correlation assumptions and correlation coefficients to be provided by the user:

$$\rho_{\delta_L^{5m60m},\varepsilon_{60L}} = \text{ANNUAL HA LOAD Forecast Error \& INTRA hour LOAD Volatility Correlation Coefficient} \quad (25)$$

$$\rho_{\delta_W^{5m60m},\varepsilon_{60W}} = \text{ANNUAL HA IR Forecast Error \& INTRA hour IR Volatility Correlation Coefficient} \quad (26)$$

$$\rho_{\varepsilon_{60L},\varepsilon_{60W}} = \text{ANNUAL HA LOAD \& IR Forecast Error Correlation Coefficient} \quad (27)$$

$$\rho_{\varepsilon_{5L},\varepsilon_{5W}} = \text{ANNUAL 5min LOAD \& IR Forecast Correlation Coefficient} \quad (28)$$

1.6 Day-Ahead Forecast and Dispatch Errors

To calculate the day-ahead forecast and dispatch errors (DAFD) we need:

$$DAFD = Load^{HA\ forecast} - Load^{DA\ forecast} + Wind^{DA\ forecast} - Wind^{HA\ forecast}$$

The above can be simplified and expressed as:

$$DAFD = L_{60}^{a} - \varepsilon_{60L} - (L_{60}^{a} - \varepsilon_{DL}) + W_{60}^{a} - \varepsilon_{DW} - (W_{60}^{a} - \varepsilon_{60W}) \quad (29)$$
$$DAFD = \varepsilon_{DL} - \varepsilon_{60L} + \varepsilon_{60W} - \varepsilon_{DW} \quad (30)$$

As in prior cases, we assume that there exists correlation between the hour-ahead and day-ahead forecast errors for wind and, separately, a correlation between the hour-ahead and day-ahead forecast errors for load. In addition, as already assumed in the load-following section, there is a correlation between the hour-ahead load and hour-ahead wind forecast error. Hence, the variance of the day-ahead forecast and dispatch errors can be expressed as:

$$\begin{aligned} Var(DAFD) &= Var(\varepsilon_{DL} - \varepsilon_{60L} + \varepsilon_{60W} - \varepsilon_{DW}) \\ &= Var(\varepsilon_{DL}) + Var(\varepsilon_{60L}) + Var(\varepsilon_{60W}) + Var(\varepsilon_{DW}) - \\ &- 2\rho_{\varepsilon_{60L},\varepsilon_{DL}}\sqrt{Var(\varepsilon_{60L})Var(\varepsilon_{DL})} - \\ &- 2\rho_{\varepsilon_{60W},\varepsilon_{DW}}\sqrt{Var(\varepsilon_{60W})Var(\varepsilon_{DW})} - \\ &- 2\rho_{\varepsilon_{60L},\varepsilon_{60W}}\sqrt{Var(\varepsilon_{60L})Var(\varepsilon_{60W})} \end{aligned} \quad (31)$$

The above result is based on the following correlation assumptions and correlation coefficients to be provided by the user:

$$\rho_{\varepsilon_{60L},\varepsilon_{DL}} = \text{ANNUAL DA Load Forecast Error and HA Load Forecast Error Correlation Coefficient} \quad (32)$$
$$\rho_{\varepsilon_{60W},\varepsilon_{DW}} = \text{ANNUAL DA IR Forecast Error and HA IR Forecast Error Correlation Coefficient} \quad (33)$$
$$\rho_{\varepsilon_{60L},\varepsilon_{60W}} = \text{ANNUAL HA LOAD \& IR Forecast Error Correlation Coefficient} \quad (34)$$

2 Calculating Variable Costs

2.1 Regulation

$$\begin{aligned} &\text{Annual Variable Cost(Regulation)} = \quad (35) \\ &[(\sum \text{seasonal REG need 1 hour of the day}) \times \text{start-up cost in Btu/kW of capacity} \times \\ &\times \text{Gas Cost} \times \text{number of start-ups per day}] + \\ &+[(\sum \text{morning peak hours} \times \text{hourly seasonal regulation need}) \times \text{Min Load Factor} \times \\ &\times ((\text{CT-CC}) \text{ HR differential}) \times \text{Gas Cost}] \times 2 + \\ &+(\text{all hours of the year}) \times (\text{Inefficiency HR Penalty}) \times \text{Gas Cost} \end{aligned}$$

2.2 Load Following

$$\begin{aligned}
&\text{Annual Variable Cost(Load Following)} = \\
&\quad [(\textstyle\sum \text{seasonal LF need 1 hour of the day}) \times \text{start-up cost in Btu/kW of capacity} \times \\
&\quad \times \text{Gas Cost} \times \text{number of start-ups per day}] + \\
&\quad +[(\textstyle\sum \text{morning peak hours} \times \text{hourly seasonal LF need}) \times \text{Min Load Factor} \times \\
&\quad \times ((\text{CT-CC) HR differential}) \times \text{Gas Cost}] \times 2
\end{aligned} \tag{36}$$

2.3 Day-Ahead Commitment

$$\begin{aligned}
&\text{Annual Variable Cost(DA Commitment)} = \\
&\quad [(\textstyle\sum \text{seasonal DA need 1 hour of the day}) \times \text{start-up cost in Btu/kW of capacity} \times \\
&\quad \times \text{Gas Cost} \times \text{number of start-ups per day}] + \\
&\quad +[(\textstyle\sum \text{morning peak hours} \times \text{hourly seasonal DA Commitment need}) \times \text{Min Load Factor} \times \\
&\quad \times ((\text{CT-CC) HR differential}) \times \text{Gas Cost}] \times 2
\end{aligned} \tag{37}$$

2.4 Ramping

First, we need to calculate the total amount of additional ramping needed in a given case with intermittent resources vs. the load-only case.

Therefore, for each morning ramp up hour, the amount of additional ramping MWhs needed is calculated as:

- 0 if the net load (with wind) ramp is negative or the net load ramp is positive but less than the load-only ramp for that hour or both
- $(Ramp_{netLoad} - Ramp_{LoadOnly}) \times 0.5$ otherwise [4]

The calculation for the ramp down hours is analogous but with the signs reversed.

Once we have the MWhs of ramp generation needed, the cost is calcualted as:

$$\begin{aligned}
&\text{Variable Cost(Ramping)} = \\
&\quad [(\text{Total MWh of Ramping Needed}) \times ((\text{CT-CC) HR differential}) \times \text{Gas Cost}]
\end{aligned} \tag{38}$$

[4] We refer to **net load** as the difference between hourly load and the hourly IR generation

3 APPENDIX

3.1 Variance Formula

$$\begin{aligned} Var\left[\sum_{i=1}^{n} a_i X_i\right] &= \\ &= \sum_{i=1}^{n} a_i^2 Var(X_i) + 2\sum_{i=1}^{n}\sum_{j=i+1}^{n} a_i a_j Cov(X_i, X_j) \\ &= \sum_{i=1}^{n} a_i^2 Var(X_i) + 2\sum_{i=1}^{n}\sum_{j=i+1}^{n} a_i a_j \rho_{X_i X_j}\sqrt{Var(X_i)}\sqrt{Var(X_i)} \end{aligned} \tag{39}$$

3.2 Composite Parameters

Since the tool allows the user to specify the parameters for up to four IR profiles, we need to calculate a composite set of forecast errors and intra-period volatility measures, while allowing for the user-specified correlation coefficients between the IR profiles. As a result, we calculate two IR composite parameter tables-one for the base year and, one for the study year.

The user-specified IR parameters are entered as percentage of installed capacity of the IR profile-therefore, calculation of the composite parameters involves a weighted sum of variances with the proper adjustments for correlations. In addition, all user-specified IR parameters (except for the correlation coefficients) are standard deviation measures and, thus, can be used in applying (39).

3.2.1 Composite IR Parameter Formula

Define the following:

$$ir_1, ir_2, ir_3, ir_4 = \text{user-specified IR parameter (as \% of IR capacity installed)-this is a standard deviation} \tag{40}$$

$$cap_1, cap_2, cap_3, cap_4 = \text{user-specified installed capacity of each IR profile (MWs)} \tag{41}$$

$$\rho_{ij} = \text{user-specified correlation coefficients for all 4 IR profiles, where } i = 1, 2, 3 \quad j = 2, 3, 4 \tag{42}$$

Hence the composite IR parameter (expressed as percentage of installed capacity) is calculated as (capacity and IR values are substituted for either base or study year):

Let:

$$
\begin{aligned}
A &= (cap_1 + cap_2 + cap_3 + cap_4) \\
B &= [(ir_1)(cap_1)]^2 + [(ir_2)(cap_2)]^2 + [(ir_3)(cap_3)]^2 + [(ir_4)(cap_4)]^2 \\
R_1 &= \rho_{12}(ir_1)(cap_1)(ir_2)(cap_2) + \rho_{13}(ir_1)(cap_1)(ir_3)(cap_3) \\
R_2 &= \rho_{14}(ir_1)(cap_1)(ir_4)(cap_4) + \rho_{23}(ir_2)(cap_2)(ir_3)(cap_3) \\
R_3 &= \rho_{24}(ir_2)(cap_2)(ir_4)(cap_4) + \rho_{34}(ir_3 cap_3)(ir_4 cap_4)
\end{aligned}
$$

Therefore, the standard deviation of the composite IR parameter is calculated as:

$$
\text{St.Dev(Composite IR Parameter)} = \sqrt{\frac{(B + 2 \times (R_1 + R_2 + R_3 + R_4))}{A}} \tag{43}
$$