Reserve requirements for 2014 VER integration

Los Angeles Department of Water and Power

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Task and objective:

This report presents the results of analysis conducted by DNV GL on behalf of the Los Angeles Department of Water and Power on load-following and regulation requirements necessary to balance 2014 VER capacity.

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1 INTRODUCTION

The Los Angeles Department of Water and Power (LADWP) retained Kema, Inc. ("DNV GL") to estimate the additional load-following and regulation reserves necessary to integrate the variable energy resource (VER) capacity in LADWP's system as of 2014. This report presents the results of DNV GL's analysis.

Higher VER capacity increases the need for load-following and regulation reserves, since dispatchable capacity must compensate for the forecast error and sub-hourly variability of the VER. At the end of 2014, LADWP had approximately 450 MW wind and 229 MW utility-scale solar in its system. This study quantifies the load-following and regulation requirements necessary to integrate this VER capacity by comparing the requirements to balance load alone with those required to balance load-less-VER.

This study follows the Maximum Generation Renewable Energy Penetration Study (MGREPS), which URS, DNV GL, and Navigant completed for LADWP in 2015. In MGREPS, DNV GL quantified load-following and regulation requirements for historical 2014 load-less-VER as well as a range of future high renewables scenarios. However, DNV GL and LADWP determined that the definitions of load-following and regulation used in MGREPS did not match what was needed to provide input into LADWP's cost of service study and rate design effort. This study uses a different methodology to quantify load-following/regulation requirements that is better suited to LADWP's needs in this regard.

For the remainder of this report, the combination of load-following and regulation requirements are referred to simply as "balancing reserve" requirements. This report does not distinguish between load-following and regulation; the combination of the two products is assumed to compensate for the difference between hour-ahead (HA) forecasts for load-less-VER (or load) and actual 1-minute load-less-VER (or load), thereby balancing both forecast error and sub-hourly variability.

Section 2 describes the methodology used to find 2014 balancing reserve requirements for load and load-less-VER. Section 3 gives results of the analysis, and Section 4 concludes.

2 METHODOLOGY

In order to evaluate the additional balancing reserve requirements necessary to integrate the VER capacity in LADWP's system in 2014, DNV GL analyzed the balancing reserve requirements necessary for load alone as well as those for load less VER. Comparing the results of these analyses gives an estimate of the additional balancing reserve requirement necessary to integrate 2014 VER capacity.

The methodology consists of three steps:

1. Simulate hour-ahead (HA) forecasts for load, wind, and solar based on hourly historical data.
2. Subtract the HA forecast wind and solar power output from the HA forecast load to obtain the HA forecast load-less-VER. Subtract historical 1-minute wind and solar power output from historical 1-minute load data to obtain 1-minute historical load-less-VER.
3. Calculate the difference between the historical 1-minute data and HA forecast for both load-less-VER and load alone. Balancing reserves must compensate for this difference.

4. Statistically analyze the results of (3) to quantify balancing reserve requirements for both load-less-VER and load alone.

2.1 Simulated hour-ahead forecasts

HA forecasts were simulated according to the following equation:

$$\hat{X} = X - \epsilon$$

in which X is the hourly historical data, ϵ is a random sample from a forecast error distribution, and $\hat{X}$ is the simulated HA forecast. Forecast error distributions were derived for HA load, wind, and solar as described in the remainder of this section.

2.1.1 Load data and forecast error distribution

LADWP provided 4-second system load data for 2014. The data were averaged to obtain 1-minute and hourly system load data.

Following the MGREPS study, the HA load forecast error was simulated as a uniformly distributed random variable between -25 MW and 25 MW. Random samples from the forecast error distribution were added to the historical hourly data to simulate HA forecasts. As an example, Figure 1 shows historical hourly and 1-minute data as well as a simulated HA forecast for system load on March 31, 2014. The forecast error is small relative to the load.

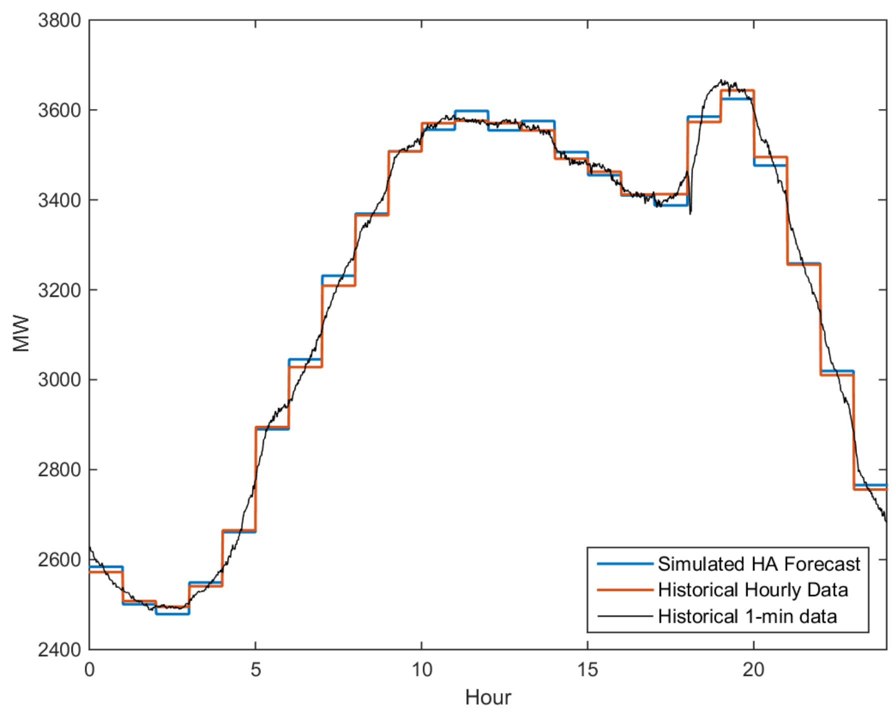


Figure 1. LADWP system load and simulated HA forecast for March 31, 2014.

2.1.2 Wind data and forecast error distributions

LADWP provided 1-minute power output data for the three wind plants in the system in 2014. Nameplate capacities are approximated as the maximum 1-minute power output in 2014 and are given in Table 1. The one-minute data was averaged to obtain hourly data.

Table 1. Estimated nameplate capacities of LADWP wind plants at the end of 2014.

Wind plant name	Capacity at the end of 2014 (MW)
Milford 1	210
Milford 2	110
Pine Tree	130

DNV GL adopted the hour-ahead forecast error assumptions from the previous MGREPS study. Table 2 shows plant-level forecast error estimates that DNV GL derived from CAISO data (as described in Appendix 2 of the MGREPS study). The LADWP system-wide estimates were derived from the plant-level estimates as described in the remainder of this section.

Table 2. Hour-ahead wind power forecast error assumptions from MGREPS study (standard deviation as a percentage of installed capacity).

	Spring	Summer	Fall	Winter
CAISO (system-wide)	4.0%	3.8%	3.2%	3.1%
Plant-level	12%	11%	9.0%	9.0%
LADWP (system-wide, 2014)	9.2%	8.5%	6.9%	6.9%

Data on the correlation of the forecast error between different wind plants was unavailable. Hour-ahead forecast errors for Milford 1 and Milford 2 were assumed to be perfectly correlated since these plants are co-located (this will provide a conservatively high estimate for balancing reserve requirements). The forecast error for Pine Tree Wind was assumed to be uncorrelated with that of the Milford plants since the plants are geographically separated.

Forecast errors were modeled as Normally distributed and curtailed at three standard deviations. The system-wide forecast error standard deviation was calculated from the plant-level data with the following equation:

$$\sigma_W = \sqrt{\sigma_p \Sigma \sigma_p^T}$$

in which σ_p is a vector containing the forecast error standard deviation for each plant in MW (equivalent to the plant capacities multiplied by the plant-level forecast error percentages in Table 2), Σ is the correlation matrix for the forecast error of the three wind plants, and σ_W is the system-wide forecast error standard deviation in MW.

Individual Monte Carlo samples of system-wide wind power forecast error were calculated as

$$\epsilon_w = \sigma_W \, \epsilon$$

in which ϵ_w is the sampled forecast error estimate, σ_W is the standard deviation of percent forecast error, and ϵ is a draw from a standard Normal distribution (with mean 0 and standard deviation 1, curtailed at three standard deviations).

The forecast error samples were further adjusted so that

$$0 \leq X_W - \epsilon_W < C_W$$

That is, the forecast power output (modelled as the difference between the actual power output for that hour, X_W , and the error sample) is never less than 0 or greater than the total system wind capacity C_W.

As an example, Figure 2 shows historical hourly and 1-minute data as well as a simulated HA forecast for system wind power output on March 31, 2014 calculated using the method described.

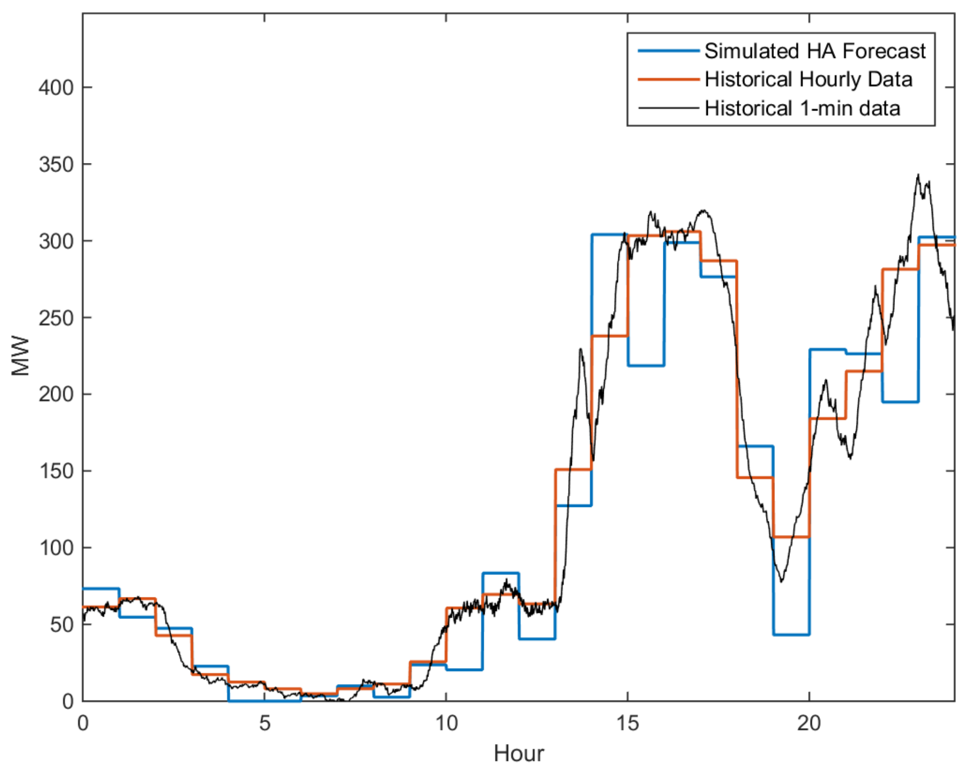


Figure 2. LADWP system wind power output and simulated HA forecast for March 31, 2014.

2.1.3 Solar power data and forecast error distributions

LADWP provided 1-minute power output data for the three solar plants in the system in 2014. Nameplate capacities are approximated as the maximum 1-minute power output in 2014 and are given in Table 3. The 1-minute data were averaged to obtain hourly data.

Copper Mountain was built over the course of 2014, such that it shows 0 power output for approximately the first four months of the year, after which its maximum power output increases incrementally through the end of the year. DNV GL synthesized 1-minute power output data for Copper Mountain, assuming a capacity of 210 MW for all of 2014, as described in Section 2.1.4.

Table 3. Estimated capacities of LADWP solar plants at the end of 2014.

Solar plant name	Capacity at the end of 2014 (MW)
Adelanto	11
Pine Tree	8
Copper Mountain	210

DNV GL adopted the hour-ahead forecast error assumptions from the previous MGREPS study. Table 4 shows plant-level forecast error estimates that DNV GL derived from CAISO data (as described in Appendix 2 of the MGREPS study). The plant-level estimates were used to derive system-wide solar power forecast error estimates for LADWP in 2014. The LADWP system-wide estimates are very close to the plant-level estimates, since almost all of the installed solar capacity is concentrated at Copper Mountain (only 19 MW are installed at Adelanto and Pine Tree – the estimates shown in Table 4 are for the end of 2014, when Copper Mountain has its maximum capacity).

Estimates are classified by Clearness Index (CI), or the ratio of the global solar radiation measured at the surface to that measured at the top of the atmosphere. In this study, CI for a single hour was approximated as the ratio between the historical solar power output for that hour and the maximum solar power output for the same hour of the day within a two-week period.

Table 4. Hour-ahead forecast error estimates for solar power output (standard deviation of forecast errors as a percent of clear-sky power output). DNV GL obtained estimates for per-plant forecast error mathematically using the aggregate CAISO estimate (encompassing 8 large PV plants and 4 distributed resources).

	0≤CI<0.2	0.2≤CI<0.5	0.5≤CI<0.8	0.8≤CI<1
CAISO (system-wide)	3.5%	6.9%	5.6%	2.3%
Plant-level	10%	19%	16%	7.0%
LADWP (system-wide, 2014)	9.3%	18%	15%	6.5%

Data on the correlation of the forecast error between different solar plants was unavailable. The correlations were assumed to be 0 since the solar plants are geographically separate.

Like the wind power forecast errors, solar power forecast errors were modeled as Normally distributed and curtailed at three standard deviations. The system-wide forecast error standard deviation was calculated from the plant-level data with the following equation:

$$\sigma_S = \sqrt{\sigma_p^{\mathrm{CI}} \Sigma (\sigma_p^{CI})^T}$$

in which σ_p^{CI} is a vector containing the forecast error standard deviation for each plant in MW for the appropriate CI value (this equivalent to the plant capacities multiplied by the relevant plant-level forecast error percentage in Table 4), Σ is the correlation matrix for the forecast error of the three solar plants, and σ_S is the system-wide forecast error standard deviation in MW. Note that σ_S can vary hour by hour depending on CI.

Individual Monte Carlo samples of system-wide solar power forecast error were calculated as

$$\epsilon_S = \sigma_S \, \epsilon$$

in which ϵ_S is the sampled forecast error estimate, σ_S is the forecast error standard deviation, and ϵ is a sample from a standard Normal distribution (with mean 0 and standard deviation 1, curtailed at three standard deviations).

The forecast error samples were further adjusted so that

$$0 \leq X_S \ - \epsilon_S < X_S^{max}$$

that is, the forecast power output (modelled as the difference between the actual power output for that hour, X_S , and the error sample) is never less than 0 or greater than the maximum (clear-sky) solar power output for that hour X_S^{max} .

As an example, Figure 3 shows historical hourly and 1-minute data as well as a simulated HA forecast for system solar power output on March 31, 2014 calculated using the method described.

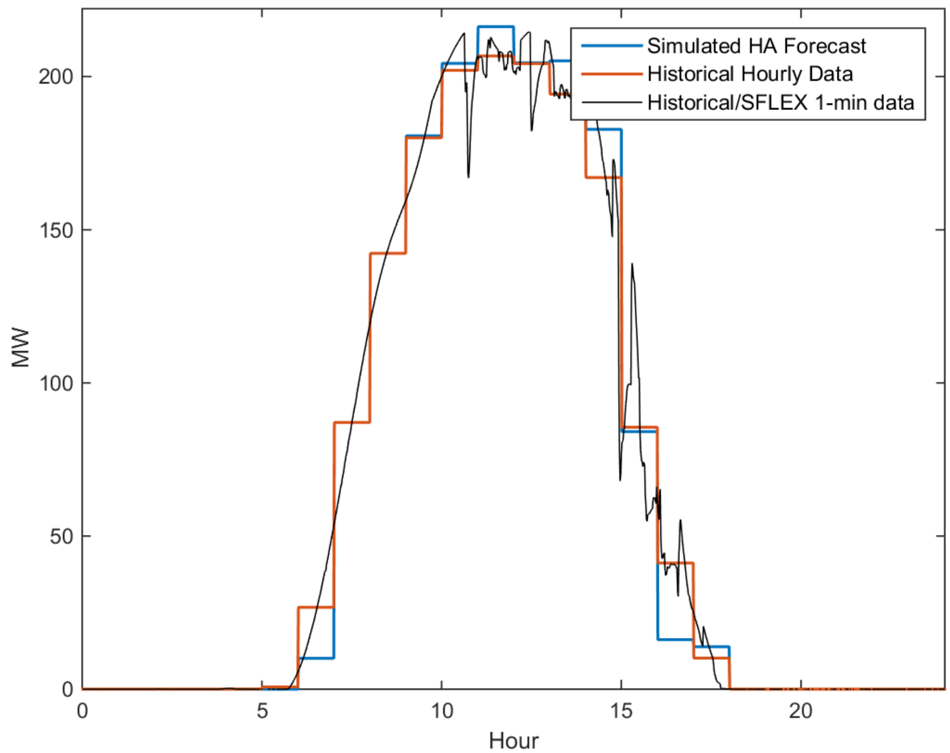


Figure 3. LADWP system solar power output and simulated HA forecast for March 31, 2014.

2.1.4 Correcting for Copper Mountain Solar capacity additions and missing data

Historical solar power output data for 2014 was pre-processed to correct for capacity additions to Copper Mountain Solar and apparent data dropouts for Adelanto and Pine Tree Solar. Figure 4 shows the 1-minute power output of Copper Mountain Solar for all of 2014, indicating clear capacity additions over time. To find the balancing reserve requirement necessary to integrate 679 MW VER (the estimated VER capacity at the end of 2014), it is necessary to synthesize 1-minute data for Copper Mountain at a capacity of 210 MW for all of 2014.

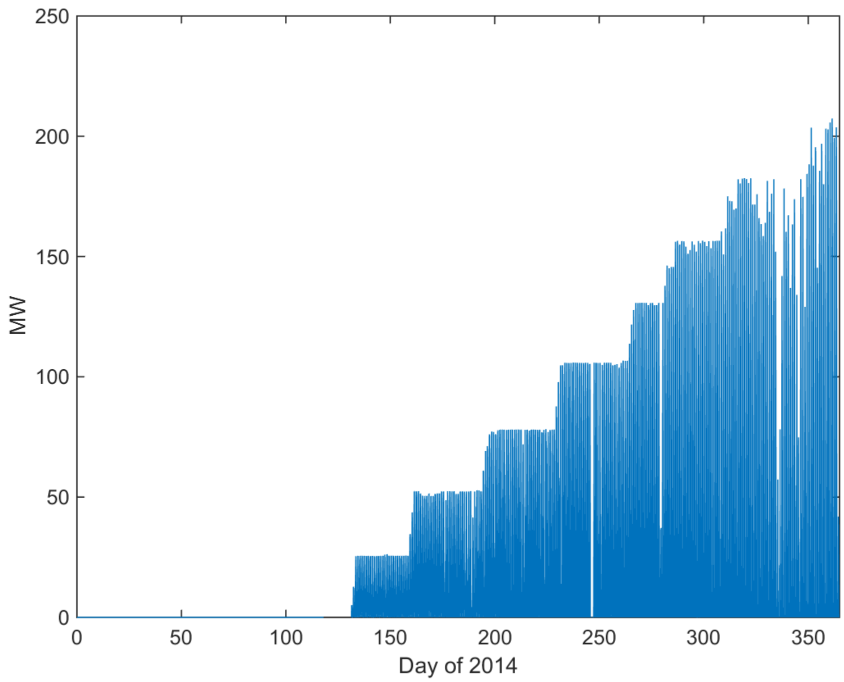


Figure 4. Historical 1-minute Copper Mountain solar power output in 2014.

The synthesized 1-minute data for Copper Mountain was obtained as follows:

1. Simulate hourly data for Copper Mountain
    a. For data after Copper Mountain has come online, scale historical hourly data up to a capacity of 210 MW
    b. For data before Copper Mountain has come online, substitute hourly summed data from Pine Tree Solar and Adelanto Solar, scaled to 210 MW
2. Simulate 1-minute data by inputting the hourly data into SFLEX, DNV GL's proprietary tool for simulating the sub-hourly variability of wind power, solar power, and load. SFLEX was calibrated to mimic the sub-hourly variability of Copper Mountain Solar in December 2014, when the plant is at its full installed capacity. SFLEX was validated against LADWP's historical data and used in MGREPS to simulate 1-minute data based on hourly profiles for future renewables scenarios. The MGREPS report contains a full description of SFLEX and validation diagnostics for LADWP.

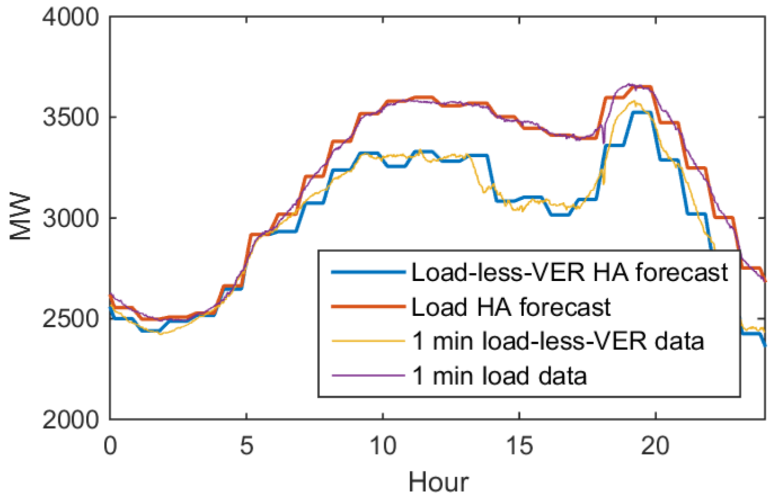
In addition to the increase in Copper Mountain solar capacity, Adelanto Solar was missing data from March 18 through April 11 and from November 24 through November 30. Pine Tree Solar was missing data from March 18 through March 26 and September 3 through September 5. The first half of each interval of missing data was filled with data for an equal number of days directly preceding the interval, and the second half of each interval was filled with data for an equal number of days directly after the interval. Wind and load data sets appeared to be complete.

2.2 Estimating load-following and regulation requirements

The historical 1-minute data and the HA forecast error models were combined to estimate 2014 balancing reserve requirements for load-less-VER as well as load alone. For each hour of 2014, HA forecasts for load, wind, and solar were simulated with the method described in Section 2.1. To simulate a load-less-VER forecast, the sum of the simulated wind and solar forecasts was subtracted from the simulated load forecast. Historical 1-minute load-less-VER data was obtained by subtracting the sum of 1-minute historical wind and solar power output from 1-minute historical load.

Figure 5 (top) shows a single day of simulated hourly load and load-less-VER forecast data as well as historical 1-minute data for March 31, 2014. Dispatchable generation capacity (scheduled based on the hourly forecast) is assumed to begin ramping 10 minutes before the hour and finish ramping 10 minutes after the hour. Balancing reserves must compensate for the difference between the dispatchable generation schedules with ramps and the actual 1-minute data.

The bottom plot of Figure 5 shows the difference between the dispatchable generation schedules (based on hourly load and VER forecasts) and the actual 1-minute data, which reflects balancing reserve requirements. This difference tends to be greater in magnitude for the load-less-VER data than the load data, due to the forecast error and sub-hourly variability introduced by additional VER capacity.



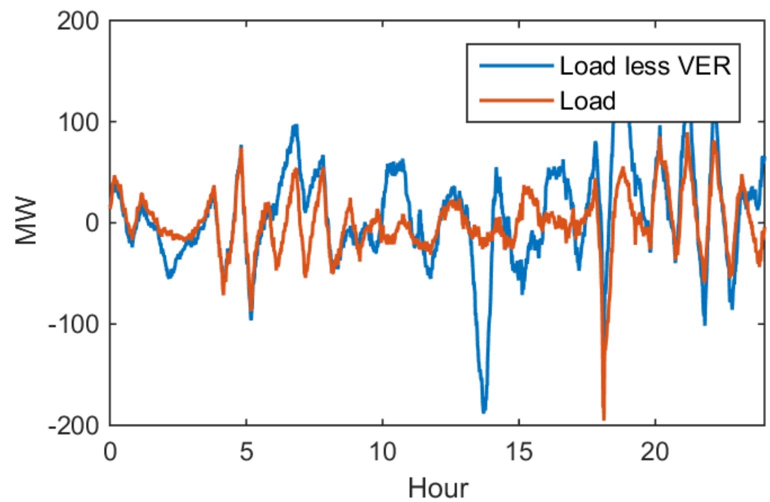


Figure 5. Top: Simulated generation schedules (based on HA forecasts) and 1-minute historical data for load and load-less-VER. Bottom: Difference between 1-minute data and dispatchable generation schedules. Figures show data for March 31, 2014.

Load-following and regulation requirements were estimated by comparing the relative frequency distributions of the difference between the simulated generation schedules/1-minute historical data for load and load-less-VER. To ensure statistical robustness, ten year-long simulations for the HA forecasts were run and used to calculate the distributions.

3 RESULTS

This section presents results on the balancing reserve requirements necessary to integrate 2014 VER capacity in LADWP. Figure 6 shows relative frequency distributions (similar to probability distributions) of the difference between the simulated generation schedules (based on HA load and VER forecasts) and historical 1-minute load and load-less VER data, as exemplified in the bottom of Figure 5. The wider distribution for load-less-VER reflects the increased sub-hourly variability and system-wide forecast error due to the VER capacity. These distributions were calculated using the simulated data for Copper Mountain Solar, such that the plant had a capacity of 210 MW for all of 2014.

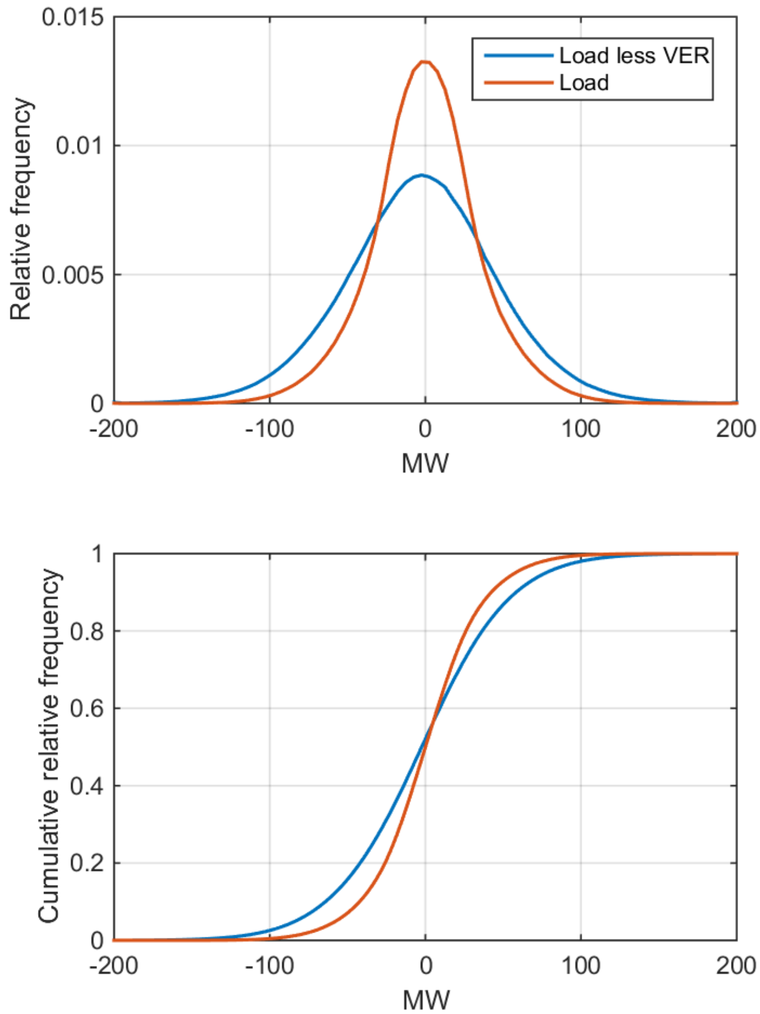


Figure 6. Relative frequency distribution (top) and cumulative relative frequency (bottom) for the difference between 1-minute historical and HA forecasts for load less VER and load.

Table 5 shows the reserve requirements necessary to cover the difference between dispatchable generation schedules (based on HA load and VER forecasts) and 1-minute actual load and load less VER for a range of percentiles. The reserves compensate for both forecast error and sub-hourly variability. Negative values indicate downward reserve requirements, and positive values indicate upward reserve requirements. LADWP has historically assumed a load-following/regulation bandwidth of +/- 25 MW. This bandwidth covers the 21^{st} to 79^{th} percentiles of the deviations between hourly forecast and 1-minute actual data for load only. To cover the same percentile range for load-less-VER, 40 MW downward reserves and 35 MW upward reserves are required.

Downward reserve requirements are slightly higher than upward reserve requirements when VER is included; this is because solar plants often generated close to clear-sky power output in 2014, such that the simulated HA forecasts could only under-predict and not over-predict power output. This leads to a slight bias towards over-predicting load-less-VER and requiring more downward reserves.

Table 5. Reserve requirements (MW) necessary to cover a given percentile of the difference between HA forecast/1-minute actual load and load-less-VER (using adjusted Copper Mountain Solar data).

Percentile	21st/79th		10th/90th		5th/95th		1st/99th		0.1/99.9	
Load	-25	25	-42	42	-58	58	-87	87	-123	122
Load-less-VER	-40	35	-64	58	-84	77	-122	115	-168	163
Difference (VER integration requirement)	-15	10	-22	16	-26	19	-35	28	-45	41

4 CONCLUSION

This study quantified balancing reserve (load-following and regulation) requirements for LADWP for 2014 based on historical load and VER data for that year. To integrate 679 MW VER in 2014, results show that an additional 15 MW of downward balancing reserves and an additional 10 MW of upward balancing reserves were necessary. This level of reserves covers the 21st/79th percentiles of deviations between 1-minute historical load-less-VER data and simulated generation schedules as the bandwidth of +/- 25 MW balancing reserves covers for these deviations in load alone. To cover 1st/99th percentile deviations, balancing reserve requirements increase from +/- 87 MW to 122 MW (downward) and 115 MW (upward) when VER is introduced.

The balancing reserve requirements found in this study are approximate. In practice, LADWP's system is not precisely balanced on a minute-by-minute basis, and hour-to-hour ramps in scheduled generation may differ from the assumption adopted here (that generators begin ramping 10 minutes before the hour and finish ramping 10 minutes after the hour). This study uses statistical analysis to give insight into the integration requirements for LADWP's 2014 VER capacity.

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