Analyzing the Impacts of Variable Renewable Resources on California Net-Load Ramp Events

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NOTICE

Analyzing the Impacts of Variable Renewable Resources on California Net-Load Ramp Events

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Abstract—**This paper characterizes the ramping features of multiple renewable resources, load and net-load in California using 2016 measured data. The goal of this analysis is to understand the interactions between variable renewable resource ramps and net-load ramps, and delineate the positive and negative impacts. The findings indicated that although the frequency and uncertainty in the system level net-load ramp occurrences increased due to variable renewable integration, there was also a decrease in the average ramp up and down magnitudes by about 20% and 30% respectively, along with decreases in their respective standard deviations by 40% and 20%. At the zonal level, the analyses also indicated a 4-5% decrease in the net-load standard deviations due to wind integration alone at various market scheduling periods. The paper finally concludes with future research needs to better integrate variable renewable ramp forecasts into system operations and planning for economic utilization of resources.**

Keywords—**Ramping, Renewables, Net-load Ramps, Flexible Ramping Product, CAISO, Ramp Forecasts, Reserves**

I. INTRODUCTION

A ramp event can be defined as large or rapid changes in power and it can appear at both generation as well as for load in the power system. Such variations in either direction (i.e., up ramp when there is an increase and down ramp when there is a decrease) must be compensated in real time using load following resources to keep the generation-load balance and the consequent system frequency response in order. In situations when serious ramp events cause generation-load imbalances, especially of the generation scarcity types with insufficient ramp capability, power markets send out high real-time prices to quickly mitigate the scarcity situation by tapping into reserves or unplanned quick start generation [1]. With increases in renewable generation penetration such as wind and solar, that induce higher amount of variability and uncertainty on the system net-load (i.e., total load minus renewable generation), it becomes challenging for the system operators to maintain the generation-load balance efficiently. To address this issue, market-based flexible ramping products (FRPs) have been proposed in the industry, which embeds foresight about the anticipated net-load ramps into the Independent System Operator's (ISO) market clearing procedures that co-optimize energy, reserves, and ramping. This in turn allows ISOs to utilize the existing ramping capabilities better by timely procurement of ramping resources in the current dispatch intervals for future needs [1]. In 2016, California ISO (CAISO) implemented FRP in its fifteen-minute real-time market (FMM) [2] and the Midcontinent ISO (MISO) in both its day-ahead and 5-min real-time markets [3].

Under the current design, FRPs are provided by fast responding peaking units and fast start units, typically gas-fired. Cui et al. [4] and Chen et al. [5] studied the feasibility and impacts of wind resources offering ramping capacity into the market clearing processes. In order for this concept to mature, it is important to understand the ramp events in the renewable generation and their interactions with the system net-load ramps better. Sevlian and Rajagopal et. al. [6] proposed an optimal ramp detection technique and analyzed the distribution of different wind power ramp features using data from the Bonneville Power Authority (BPA) and NREL Western Integration Dataset. Kamath [7] showed the effectiveness of a simple statistical analysis on the characterizations of wind generation ramp events, including distributions of severity levels, start time within the day and occurrence by month from a BPA dataset. Based on systematic studies on wind power changes at different time steps, Wan [8] studied the statistics of wind power ramp events from ERCOT data and inspected their impacts on the system net-load ramps. However, all of these works only focused on detection and characterization of wind ramp events, and there is a dearth of works that can relate the impact of variable renewable resource ramps on the system net-load ramps and understand the changes in their summary statistics.

Thus, the goal of this paper is to analyze the ramp events in the California system's load and net-load data, and quantify the impact of variable renewable ramps on net-load ramps from both negative and positive perspectives. For this purpose, the optimized swinging door algorithm (OpSDA) developed in [9] was used in this study to detect and assess the ramp events and their features such as start times, magnitudes, duration and rates. Based on the ramp characterizations shown in Sections II (load and net-load) and III (renewable resources), the possibilities of future power market innovations for variable renewable ramp forecast integration are discussed in Section IV. Finally, Section V presents conclusions.

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II. LOAD AND NET-LOAD RAMPS CHARACTERIZATION

The 2016 California system measured data, at 1 min resolution [10], was used to analyze the ramp up and ramp down events for load and net-load. The net-load is defined as system load minus renewable generation, including distributed generation, solar PVs, solar thermal, and wind power in California. Table I shows the number of ramp events detected in the load and net-load data (using OpSDA [9], with a qualifying ramp event defined as 5% of the total load), where we observe an increase in the net-load ramp events influenced by the addition of renewable generation. Fig. 1 shows the distributions of ramp event start times across the 24-hour period, where we observe that the ramp event occurrences are relatively less predictable in the net-load data (i.e., occurring throughout the day) compared to the load data which had ramps mostly happening during morning and evening hours.

TABLE I NUMBER OF RAMP EVENTS IN 2016 CAISO LOAD & NETLOAD DATA

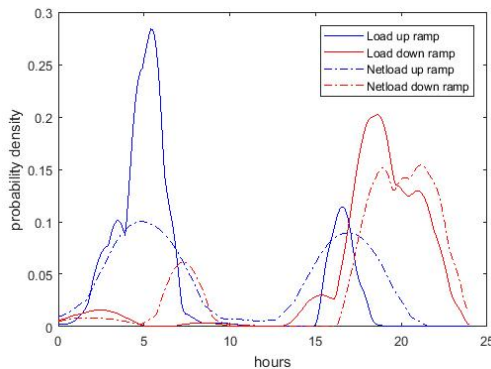|	Load	Net Load
Ramp Up	313	731
Ramp Down	245	622

Fig. 1 Daily Distributions of CAISO Ramp Up and Down Event Start Times
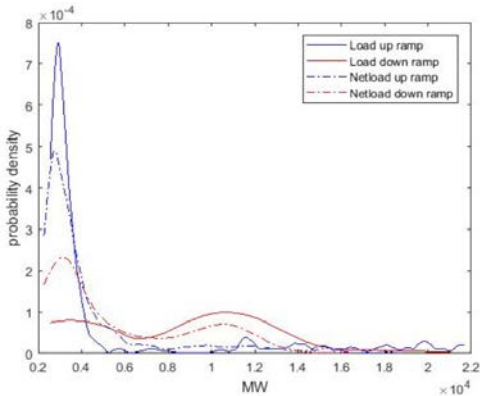

Fig. 2 Distributions of CAISO Ramp Up and Down Event Magnitudes

However, it is also interesting to note from Fig. 1 that there are less ramp events in the net-load data during early morning (5-7 am) and evening peak hours (16-18 pm). Upon analyzing ramp magnitudes, Fig. 2 shows that the probability of certain magnitudes (around 8-14 GW, 18-20 GW) decreases in the net-load ramp data compared to the load data. The summary

statistics in Table II for ramp magnitudes and rates further corroborate this finding, where we can observe that the ramps in the net-load have lower maximum and average magnitudes and rates, along with a smaller standard deviations compared to the load ramps. This indicates that the ramp magnitude and rates in net-load is distributed in lower values with a smaller range. Therefore, though the integration of renewables has increased the number of ramp events and their uncertainties, there are times when they seem to alleviate the net-load ramps in either direction, thereby implicitly providing ramping capability to the grid for reliable operation.

TABLE II 2016 CAISO LOAD AND NET-LOAD RAMP STATISTICS

	Load (w/o renewables)		Net load (% change)	
	Up	*Down*	*Up*	*Down*
Ramp magnitude (MW)				
Max	21,704	21,058	18,400	16,594
Average	5,406	8,075	4,317(-20%)	5,694(-30%)
Std. Dev.	5,077	4,227	2,894(-43%)	3,349(-20%)
Ramp rate (MW/min)				
Max	3,540	3,692	3,537	3,134
Average	104	118	80(-28%)	69(-41%)
Std. Dev.	370	439	252(-32%)	264(-40%)

III. RENEWABLE GENERATION RAMPS CHARACTERIZATION

Figure 3 shows the ramp up (left) and down (right) events start time distributions for different renewable generation, that include distributed generation (DG), PV Solar (PV), Thermal Solar (TS) and Wind. One can draw the following inferences about the aggregated impact of solar-dependent resources on net-load ramps from Figs 1 and 3:

- *Negative impacts:* The worsening of ramp up requirements in the net-load data during the evening 15-19 hours in Fig. 1 may be primarily due to solar-dependent resources as they tend to ramp down during those hours as seen in Fig. 3 (right).

- *Positive impacts:* However, reduction in the ramp up and down magnitudes in the net-load data compared to load data (Fig. 1) during morning and evening hours respectively may be primarily attributed to the solar-based variable renewable resources, which ramp up in the morning and ramp down in the afternoon (Fig. 3).

Wind resources, however, are different from the rest of the renewable resources, in that the majority of ramp up start times is in the evening, and ramp down start times is in the early morning. The following inferences can be drawn about their aggregated impact on net-load ramping events:

- *Negative impacts*: Comparing Figs. 1 and 3, during morning hours when load is expected to ramp up; aggregate wind resources ramping down may have an exacerbating effect. Additionally, the spread out nature of wind ramping events in Fig. 3 throughout the day may

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contribute to the similar observation in the net-load ramp events and increase uncertainties

- *Positive impacts*: Comparing Figs. 1 and 3, load and wind ramp up events coincide to some extent during evening
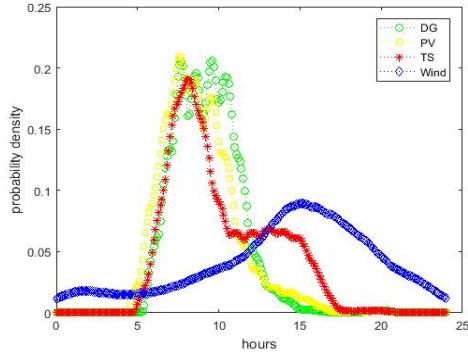
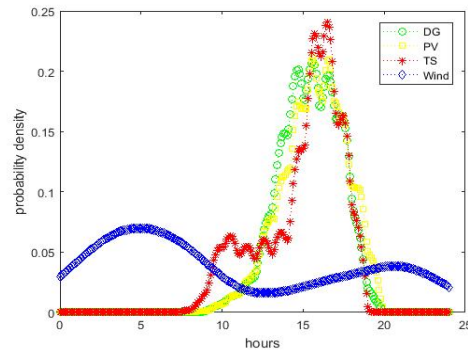hours, when the system could possibly face ramping capability limitations.

Fig. 3 Distributions of Renewable Ramp Start Times: Ramp up (left) and Ramp down (right)

To further confirm the above observations, investigations at the zonal level were performed. In this analysis, load ramp features were compared with wind affected net-load ramp features (i.e., Net-load$_w$ or Netload (wind) defined as load minus wind) at three different reserve zones in California, pertaining to the Pacific Gas & Electric (PG&E) bay area (with ~3% wind by capacity), the Sacramento Municipal Utility District (SMUD) (with no wind) and the San Diego Gas & Electric (SDGE) (with ~9% wind by capacity) utility regions. Based on the work in [11], yearly load and renewable resource data at 1 min-resolution for the three CAISO zones were used to estimate the load and wind resource distribution factors among the three zones, which was applied to the 2016 California system time series data [10]. To study the impact of wind generation on net-load ramps, three different maximum instantaneous wind energy penetration levels (estimated as the largest wind to load ratio in the time series data) were chosen, i.e., 15% (2016 CAISO system data), 30%, and 50%.
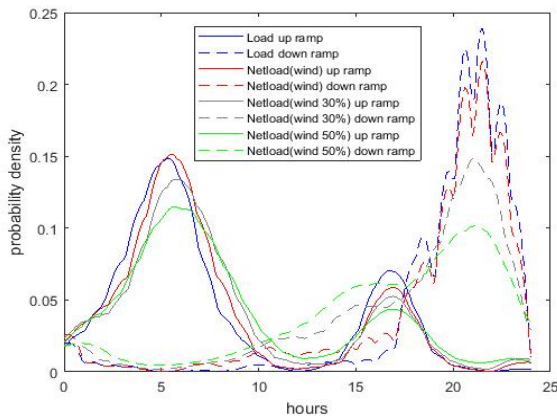

Fig. 4 California Zone 3 Ramp Start Time Distribution of Load and Net-load(wind) at Different Wind Penetration Levels

Figure 4 shows the ramp start time distribution of load and net-load$_w$ at different wind penetration levels in zone 3. When the penetration level increases from 0% indicated by blue lines (load data) to 50% indicated by green lines, we observe that

although wind resources do spread the ramp events across the day (8-15 hours), they do contribute to the decrease in the frequencies of ramping events, especially during early morning (4-7) and peak evening hours (16-18) for ramp up events, and late evening/night hours (20-23) for ramp down events. Table III shows the statistics of ramp up and ramp down magnitudes for load and net-load$_w$ at different wind penetrations in zone 3. Though the number of net load ramps does increase with the increase in wind penetration level (doubles at 30% wind and almost triples at 50% wind), the values of ramp magnitude statistics including the average and standard deviations decrease (decreases by 40% and 50% for ramp up, and 28% and 33% for ramp down under 30% and 50% wind penetrations respectively). These are further evidences that wind energy in zone 3 is indeed helping the system by reducing ramps, including during peak hours.

TABLE III ZONE 3 RAMP MAGNITUDE STATISTICS AT DIFFERENT WIND PENETRATIONS (% CHANGE FROM LOAD ALSO SHOWN)

	Load (MW)	Netloadw 15% (MW)	Netloadw 30% (MW)	Netloadw 50% (MW)
Ramp Up				
Average	1,514.2	1,283.7(-15%)	1,204.7(-20%)	1,194.6(-21%)
Std. Dev.	1,062.3	770.8 (-27%)	613.6 (-42%)	520.6 (-51%)
Number	731	1,018	1,423	1,966
Ramp Down				
Average	1,271.4	1,209.5 (-5%)	1,172.8 (-8%)	1,179.9 (-7%)
Std. Dev.	743.7	656.9 (-12%)	531.7 (-28%)	495.8 (-33%)
Number	777	1,001	1,433	1,963

IV. DISCUSSION ON FUTURE NEEDS: BETTER INTEGRATION OF VARIABLE RENEWABLE RAMP FORECASTS

The analyses in Sections II and III indicate a need for better integration of variable renewable ramp forecast information into the market operations and planning tools. Currently, average forecasts of variable renewable generation at different time intervals suitable for different market clearing processes are accounted, i.e., day-ahead forecasts for day-ahead market, a few hours-ahead forecasts for look-ahead reliability unit commitments, and intra-hour ahead (15-min and 5-min)

forecasts for real-time markets. Though average forecasts of renewable generation will provide an estimation of the expected ramps, nevertheless, markets have to explicitly take into account the accurate ramp forecasts of renewables in order to 1) better cope with their anticipated negative influences on the net-load, and 2) be in a position to take advantage of their positive impacts on net-load ramps that could alleviate the reserve needs. In this context, we envision at least two kinds of integrations of renewable ramp forecasts.

A. Better FRP procurements using net-load ramp forecasts

ISOs that have implemented FRPs estimate the ramping capability procurements for their day-ahead and real-time markets based on day-ahead and real-time net-load forecasts, respectively. In addition to the net-load ramp forecast, the ramping requirements are also informed by ramp uncertainties (typically a function of standard deviations in historical net-load ramp data). Therefore, any improvement in the renewable generation ramp forecasts will directly impact the net-load ramp forecasts and consequently the FRP procurement in the markets. This can be observed from the standard deviations of the 5-min, 15-min, and 1-hour net-load ramps shown in Table IV. The standard deviations at various time-intervals decrease in the net-load$_w$ data under 50% wind penetration compared to 15% wind penetration data (~1% reduction in zone 1, ~4-5% reduction in zone 3 and ~2% reduction in system (zone 2 has no wind)), which will reduce the ramp procurement needs in the respective markets and consequently reduce the reserve costs from conventional generation and the system production costs [4]. Therefore, precise information of renewable ramp forecasts and their uncertainties through advanced probabilistic forecasts [12], and the integration of such information to extract accurate net-load ramp forecasts will likely benefit system economics.

TABLE IV Net-Load$_w$ Ramp Standard Deviation: 15% vs. 50% Wind

Region	5-min	15-min	1-hour
CAISO	141.70 vs. 138.99	213.81 vs. 209.96	392.30 vs. 386.84
Zone 1	102.19 vs. 101.22	126.86 vs. 125.64	200.16 vs. 198.49
Zone 2	66.63 vs. 66.63	75.73 vs. 75.73	107.31 vs. 107.31
Zone 3	77.49 vs. 74.39	92.70 vs. 87.99	135.98 vs. 129.07

B. Plant-level ramp forecasts for situational awareness and ramp products from variable renewable generation

The previous discussion was from the system perspective, where aggregated wind and net-load ramp forecasts are to be used. Under increasing levels of variable renewable penetrations, plant-level ramp forecasts will also be important. Already, the Electric Reliability Council of Texas (ERCOT) has implemented programs to gain visibility into renewable resources in their energy management system (EMS) that will inform the operators about impending wind ramping events

along with their probabilities [13]. This feature provides necessary situational awareness of variable renewables for the operators to take timely corrective actions including calling on unplanned quick start units to offset any ramp up deficits. However, as discussed before, there are scenarios when certain renewable resource plants also provide positive impacts on system net-load ramps. Therefore, future EMS applications will benefit from having precise plant-level ramp forecast information, along with associated uncertainties in the form of probabilistic forecasts [14], which will enable system operators to gain accurate foresight into such situations. Such abilities could also enable operators in the real-time EMS environment to use variable renewable ramps better, including strategically curtailing certain plants in order to offset down-ramp deficits (instead of cycling a conventional plant), and then compensate the respective renewable plant with lost opportunity cost or FRP clearing prices.

Additionally, integrating plant-level ramp forecast information in the planning and market dispatch processes could enable variable renewables to offer their services for the flexible ramping product explicitly, unlike the conventional idea of implicitly accounting for their impacts on net-load ramping requirements (as discussed in Section IV.A). Figure 5 shows probability distributions of wind ramp start times, magnitudes and duration based on 2013 simulated wind power data at 5-min resolution from NREL's WIND toolkit [15] over 24 hrs. The selected wind site is from a city named Felicity, on the border between California and Mexico, with a site ID 14960 in the WIND toolkit, a capacity of 16 MW, a wind speed of 6.36m/s, and a capacity factor of 0.33. We can observe that the peaks of the distribution curve of ramp up events are in the early morning (around 4 am to 8 am) while the peaks of the distribution curve of ramp down events are in the afternoon (13-15 pm), except for in the Summer. The ramp up events from this plant in the morning are beneficial to the system since the system load also ramps up at the same time, as seen in Fig. 1. While looking at the aggregated wind ramp up start times in Fig. 3, wind resources contributions to ramping up events in the morning hours seemed trivial, but in looking at this plant-level information, one can see opportunities for this plant to offer its ramping capacity explicitly into the FRP. Fig. 5 shows that this wind plant can provide a ramping capability of 4-6 MW (~32% of 16 MW plant) with high probability, and that some of these ramps could also last for hours, thereby creating opportunity for this and any other wind plants with correlated outputs to offer their ramping capability explicitly for FRP services, thereby having a chance to gain additional revenues from FRP marginal clearing prices. Apart from aiding system ramps when a particular wind plant's ramp is forecasted to be in sync with the load ramps, wind generation can also consider controlling their outputs or ramp rates under situations when a wind resource's ramp is forecasted to exacerbate the system ramping needs (i.e., wind ramps in opposite direction to net-load). One such example is when wind resources can consider strategically

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curtailing the wind power and thereby provide down-ramp under situations when system down-ramp capability is limited, under situation when it is economically more attractive than providing power to the energy market.

Therefore, having accurate forecasts of plant-level ramps and their uncertainties will open the door for better understanding of the synergies between variable renewable generation and load ramps, and even utilizing the renewable ramps for grid services. Consequently, ramping provisions by individual renewable plants will reduce the FRP needs from conventional units and reduce total system production costs.
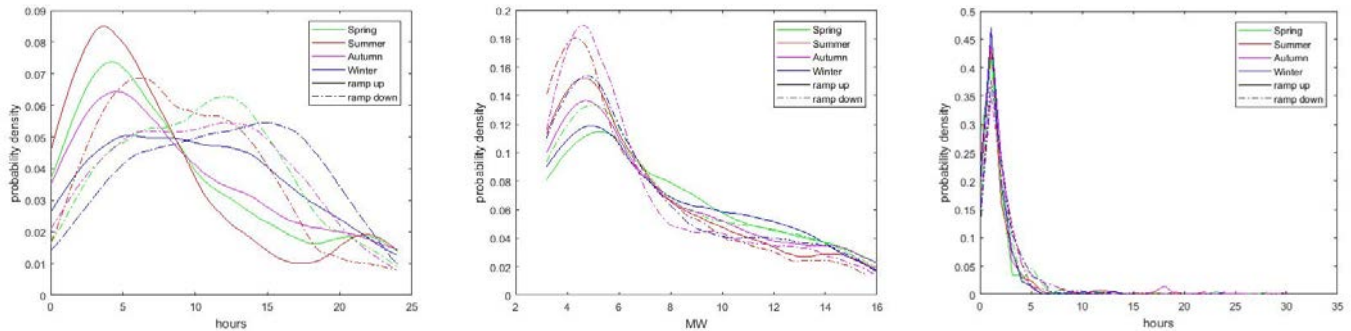

Fig. 5 Distributions of Wind Site Ramp: 1) Start Time, 2) Magnitude, and 3) Duration

V. CONCLUSIONS

This paper presented an analysis of the impacts of variable renewable generation ramps on the system net-load ramps, taking California 2016 measured data as an example and extracting ramp features using the optimized swinging door algorithm. The analysis showed that integration of variable renewables definitely increased the overall annual frequencies of ramp events and uncertainties related to their occurrences throughout the day. Nevertheless, during certain ramping challenged situations like early morning or evening hours, renewable generation ramps seemed to implicitly provide support to net-load ramps and decrease the magnitudes and ramp rates of net load. The summary statistics showed the average of system aggregate net-load ramps to decrease by 20% in magnitude for ramp ups and 30% for ramp downs, with their standard deviations decreasing by 40% and 20% respectively.

Upon analyzing the solar and wind resources separately, it was observed that solar ramps had positive influences on overall ne-load ramps during morning and early evening hours when their trend coincided with diurnal load, except during late evening hours when net-load ramp up was exacerbated due to solar ramp down. On the other hand, wind resources seemed to contribute to the decrease in the frequencies of ramping events, especially during early morning and late evening hours for ramp up events, and late evening/night hours for ramp down events, thereby providing implicit support to the grid when solar ramped down. A further zonal level investigation of wind ramp impacts on California net-load showed that in zone 3 (depicting SDGE with higher wind capacity) wind ramps could decrease ramp standard deviations by up to 4-5% at 5-min, 15-min, and 1-hour intervals, which would mean the required ramping reserve procurements will be reduced.

All of these analyses indicated a need for better integration of variable renewable ramp forecasts information, including their uncertainties via probabilistic forecasts, into the market operations and planning tools, both at the individual plant level, as well as aggregated regional or system level. This will enable better utilization of existing ramping capabilities in the grid, including from the variable renewable resources, reducing unplanned quick starts, reducing system production costs, and finally achieving more efficient markets.

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