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Using Simple Statistical Analysis of Historical Data to Understand Wind Ramp Events

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Using Simple Statistical Analysis of Historical Data to Understand Wind Ramp Events

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Abstract

As renewable resources start providing an increasingly larger percentage of our energy needs, we need to improve our understanding of these intermittent resources so we can manage them better. In the case of wind resources, large unscheduled changes in the energy output, called ramp events, make it challenging to keep the load and the generation balanced. In this report, we show that simple statistical analysis of the historical data on wind energy generation can provide insights into these ramp events. In particular, this analysis can help answer questions such as the time period during the day when these events are likely to occur, the relative severity of positive and negative ramps, and the frequency of their occurrence. As there are several ways in which ramp events can be defined and counted, we also conduct a detailed study comparing different options. Our results indicate that the statistics are relatively insensitive to these choices, but depend on utility-specific factors, such as the magnitude of the ramp and the time interval over which this change occurs. These factors reflect the challenges faced by schedulers and operators in keeping the load and generation balanced and can change over the years. We conduct our analysis using data from wind farms in the Tehachapi Pass region in Southern California and the Columbia Basin region in Northern Oregon; while the results for other regions are likely to be different, the report describes the benefits of conducting simple statistical analysis on wind generation data and the insights that can be gained through such analysis.

Contents

1 Introduction

A desire for energy independence from fossil fuels, along with various climate change initiatives, have resulted in an increasing interest in renewable sources of energy, such as wind and solar. However, the intermittent nature of these sources can make them difficult to manage. In addition, for renewables such as wind, the occurrence of ramp events, where the energy generated suddenly increases or decreases rapidly in response to changes in wind velocity, can lead to challenges in keeping the load and generation balanced at all times.

In the past, the percentage of energy from wind sources, relative to the peak load, was small. For example, in 2006, the California Independent System Operator (CaISO) managed over 2200 MW of wind generation, which was only 4% of the total generation resources in the area [5]. The Tehachapi area in Southern California, which is one of the largest wind generation areas under CaISO, had 740MW installed capacity. At this capacity, the ramp events are relatively small. So, it is relatively easy to keep the load balanced, and the generation required to back up wind power is small as well.

However, with increasing wind penetration, the size of the ramp events has also increased. For example, the installed wind capacity in the Bonneville Power Administration (BPA) is currently over 2000 MW and is expected to increase to over 3000 MW by 2010, when it will be 30% of the peak load. At this capacity, the wind ramps can be quite large, changing by nearly 1000 MW in an hour, and it becomes more of a challenge to balance the load and the generation. The control room operators and schedulers now have to monitor the wind generation more closely, and plan for enough backup generation to meet the load, especially during downward ramp events when there is an unscheduled decrease in wind generation by a large amount in a short time. Positive ramps can also cause problems if the transmission lines cannot handle the sudden increase in energy or if the wind energy is being traded in a market where it is a “must take” resource, resulting in problems backing off other generation during a positive ramp.

There are several ways in which we can better manage this intermittent nature of wind resources. These include more accurate wind generation forecasts as well as an improved understanding of the ramp events. In this report, we show that we can gain insights into ramp events by analyzing recent historical data on actual generation from wind farms. Specifically, simple statistics extracted from the data can answer questions, such as, do ramps occur more frequently in the mornings or evenings, do the negative ramps occur as frequently as the positive ramps and are they as severe, is there a difference between various definitions of a ramp, and do severe ramps occur rarely or are they relatively frequent?

This report is organized as follows. First, in Section 2, we describe the data used in the analysis. We consider wind generation in two regions - the 2007-2008 data from the Tehachapi Pass in Southern California and the 2007-2009 data from the Columbia Basin in Northern Oregon. This is followed in Section 3 by details on the preprocessing of the data, the different definitions of ramp events, and the different options for counting the ramp events. In Section 4, we investigate the effects of smoothing the data during pre-processing and determine if the different definitions and counting options make a difference in the results. Next, in Section 5, we summarize various ramp event statistics for the two regions under consideration in this report, along with our observations. We conclude with a summary.

This report is an expanded and enhanced version of earlier work which appears in [6].

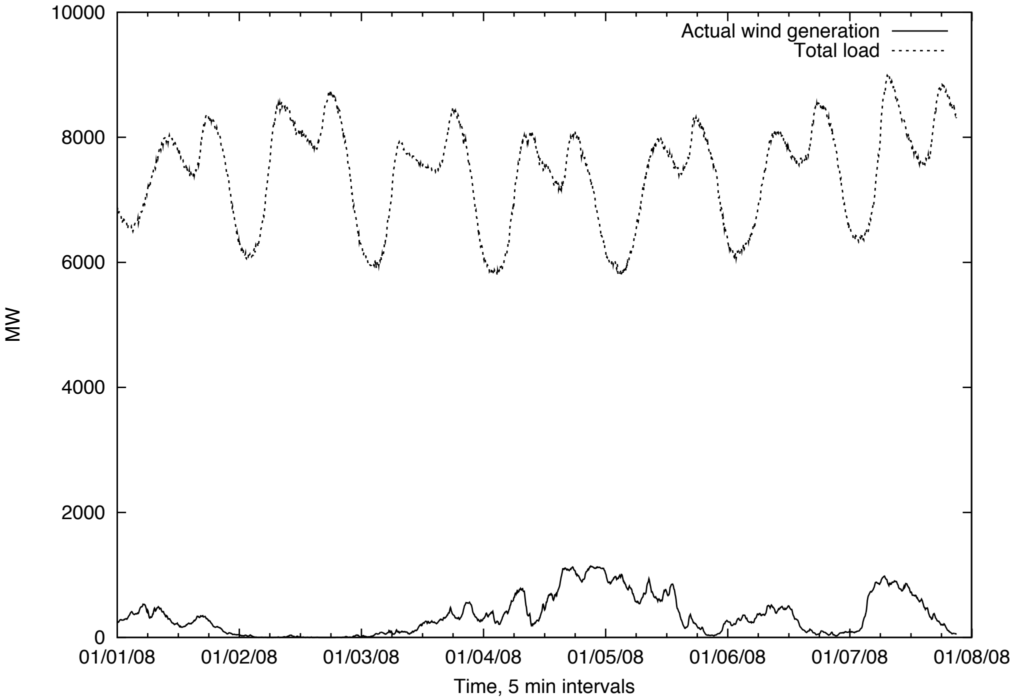


Figure 1: The load (top curve) and the wind generation (bottom curve) for the first week of January 2008 for the BPA balancing area. Note the daily periodicity in the load curve.

2 Description of the data

We conduct our study of ramp events using actual wind generation data from Southern California Edison (SCE) for the years 2007-2008 and Bonneville Power Administration (BPA) for the years 2007-2009. We chose data from the recent past as any analysis of these data is likely to be more relevant. Further, the last few years have seen a large increase in installed wind power in BPA balancing region, increasing from 700 MW in 2006-2007 to over 1300 MW in 2008 and more than 2000 MW in 2009 [1, 2]. This increase in capacity is the result of new wind farms being connected to the grid or existing installations being upgraded with more efficient turbines. A similar increase is also expected in the Tehachapi region in the future.

The BPA data available for the period 2007-2009 are the total generation from all the wind farms in the BPA balancing area around the Columbia Basin [3]. The data are sampled at 5 minute intervals, and for each data point, include the time (year, month, day, hour and minute), the actual wind generation, and the total load at that time. Figure 1 shows the wind energy generated and the load for the first week of January 2008 for the BPA balancing area. Note the daily periodicity in load; however, there is no such periodicity in the wind energy generation. Figure 2 is a longer sequence for the wind energy for the month of January 2008. Note the intermittent nature of the energy generated, with some days having no generation, while on other days, it can reach as high as 1200 MW.

From July 2008 onward, the BPA data also include the wind energy scheduled by the operators for each time interval; these data are not considered in the present analysis.

The SCE data for wind generation are sampled more coarsely than the BPA data. These

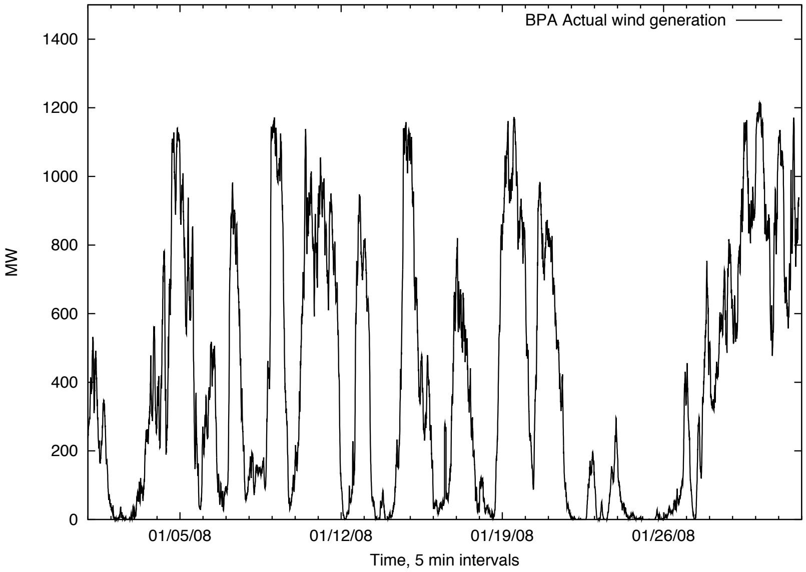


Figure 2: The wind generation for January 2008 for the BPA balancing area.

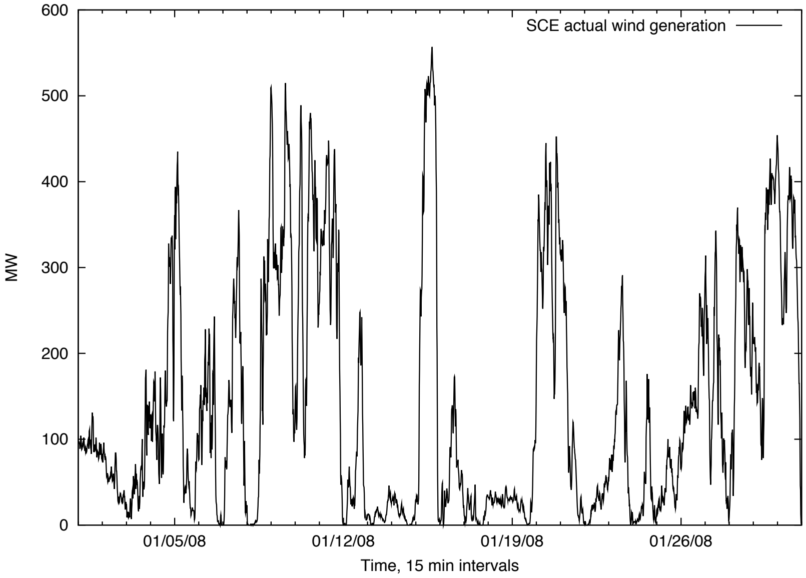


Figure 3: The wind generation for January 2008 for the Tehachapi Pass area.

data are available at 15 minute intervals for the Vincent and Antelope regions of the Tehachapi Pass in Southern California. As these two regions are close by, their wind generation is very similar, so we consider the sum of the generation in our analysis. Figure 3 is the wind energy for the month of January 2008 for SCE. Note again the intermittent nature of the generation, with some days having no generation, while on other days, it can reach over 500 MW.

The intent of the work presented in this paper is to show that we can gain insights into wind ramp events through simple statistical analysis of the wind generation data. However, we caution that the results of this analysis must be interpreted with care as they reflect the conditions for specific years for two specific regions, namely, the Columbia Basin and the Tehachapi Pass. The results may be different for other regions and, with the changing global climate, are also likely to change for a region in the long term.

3 Analysis of the data

Our analysis of ramp events consists of three main steps: data pre-processing, ramp definition, and counting the ramp events to extract various statistics. There are several ways of implementing these steps which we discuss next in more detail.

3.1 Pre-processing the data

There are several aspects to pre-processing the data. The first is to bring all the data to a consistent format, with each time interval described by three variables: the date (month, day, and year), the time (in hours and minutes), and the actual wind generation. In the case of BPA data, we also have access to the total load at each time interval; since this is not used in the present analysis, it is ignored.

In addition, we need to check the quality of the data as they can have missing values or incorrect values, such as negative values for wind generation. We found that the BPA data had missing values; sometimes, only one or two consecutive time intervals were missing, while in other cases, an hour or more of data were missing. These missing values were represented as blanks in the original data. For our analysis, if only one or two values were missing, they were filled in via interpolation. If more than two consecutive values were missing, they were replaced by -9999, and ignored in any further analysis. In the case of SCE data, the generation from the Antelope region occasionally had small negative values. These were replaced by zero before being added to the data from the corresponding interval from the Vincent region.

Finally, as the time series data are noisy, we can smooth them before identifying the ramp events. There are different ways of reducing the noise in the data, for example, by using simple mean or Gaussian filters, or the more complex wavelets. These filters can be applied more than once to the data, resulting in greater smoothing. As we show in Section 4.1, care must be taken while smoothing the data to ensure that we do not degrade the signal in the process of reducing the noise.

3.2 Defining a ramp event

Once the data have been cleaned, brought to a consistent format, and smoothed (if necessary), we need to identify the ramp events in the data. Though it is often easy to identify ramp events visually, there is no standard way in which such events are defined mathematically [4].

Therefore there are different ways in which we can interpret a "large increase or decrease in energy output in a short time." In this report, we consider three definitions:

- **Ramp definition 1:** In this simple definition, a ramp event is considered to occur at the start of an interval if the magnitude of the increase or decrease in generation at a time ΔT ahead of the interval is greater than a pre-defined threshold, Tr_{MW}:

  $$|MW(T + \Delta T) - MW(T)| > Tr_{MW} \tag{1}$$

- **Ramp definition 2:** Since definition 1 focuses only on the end points of the interval being considered, it can miss ramp events if they occur between the two endpoints, though the endpoints themselves may not exhibit a large change in magnitude. Our second definition considers the minimum and maximum value of wind generation between the two endpoints (inclusive):

  $$max(MW[T, T + \Delta T]) - min(MW[T, T + \Delta T]) > Tr_{MW} \tag{2}$$

- **Ramp definition 3:** This definition is based on the slope of the energy over a fixed time interval, say, 30 minutes. This reflects the visual perception of a ramp event as "steep gradients in power production" [4]. There are several ways in which this definition can be implemented. One option is to require that the slope of the generation (MW/min) be greater than a threshold for all intervals in T to $(T + \Delta T)$. However, this will not correctly identify ramps where one of the intervals in T to $(T + \Delta T)$ has a very large slope, while the other intervals have a slope below the threshold. An alternative is to consider the average slope of the intervals in T to $(T+\Delta T)$ and require that it be greater than a threshold:

  $$\frac{1}{n} \sum_{T_i \in [T, T+\Delta T]} \mathrm{sl}(T_i) > Tr_{sl} \tag{3}$$

  where n is the number of intervals in $[T, T + \Delta T]$ and $\mathrm{sl}(T_i)$ is the slope at the i-th interval. In our work, we use central differencing to define the slope at T_i:

  $$\mathrm{sl}(T_i) = \frac{1}{2}(MW(T_{i+1}) - MW(T_{i-1})) \tag{4}$$

  Note that the calculation of the slope can be sensitive to noise in the data. This definition is therefore likely to benefit from smoothing, though as observed earlier, smoothing of the data must be done with care, a topic we discuss further in Section 4.1.

The ramp is considered a positive or negative ramp depending on whether the generation increases or decreases over time. For example, Figure 4 shows large positive and negative ramps around 3:45pm on June 21, 2008 in the BPA data. From the hour prior, the generation increases by 667MW to a peak of 855MW and then drops by 577MW an hour later. Negative ramps are usually more challenging as the operators have to find other generation to replace the decrease in generation from wind sources and keep the load balanced. Positive ramps too can be an issue if the transmission lines cannot handle the sudden increase in energy or if the energy markets treat wind generation as a "must take" resource and there are problems in reducing other generation during a positive ramp.

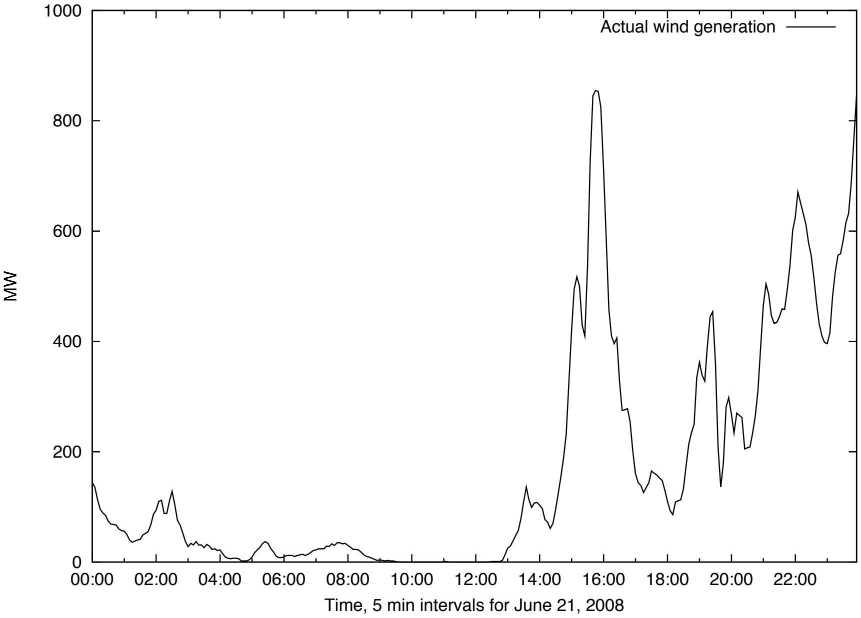


Figure 4: The large positive and negative ramps in the hour just before and after 3:45pm on June 21, 2008 for the BPA data.

Ramp definitions 1 and 2 are directly dependent on two parameters: the threshold, Tr_{MW}, and the time interval, ΔT. For definition 3, which is defined using the slope of the generation, the two thresholds are combined into one as $Tr_{sl} = Tr_{MW}/\Delta T$. This results in a linear change of Tr_{MW} occurring over ΔT being identified as a ramp by all three definitions.

The values of ΔT chosen for the ramp events are typically 15 minutes, 30 minutes, and 1 hour. The choice of the threshold Tr_{MW} is more difficult. For definitions 1 and 2, which are based on the generation, we can set the threshold to be an absolute value, say, 100 MW for a 15 min ramp or 450 MW for a 60 min ramp. This value is system dependent and could be chosen, for example, to reflect the amount of energy that is difficult to procure in the given time interval to keep the system balanced. We can also define this threshold as a percentage, say 20%, of the installed nameplate capacity for a wind farm. The issue with this definition is that we need to know the installed capacity at any time. This is likely to vary over time as existing turbines are upgraded or shut down for repairs or maintenance. In the former case, an event which qualified as a ramp event on one day, may not be a ramp event on another day with a higher nameplate capacity, though the challenges of managing a ramp of that magnitude would be the same for both days. In the latter case, we would have false alarms, with changes which were manageable one day, being identified as ramps the next day, when the threshold is smaller due to a reduction in nameplate capacity.

In light of this, we chose an absolute threshold value for our analysis and obtained statistics with various values to see if the results are different. In practice, this threshold should be selected appropriately based on input from system operators and schedulers. It would likely be different for different regions and could vary over the years, evolving to match the changes in the generation mix at a utility.

The ramp definitions considered in this report indicate when an interval can be considered to be the start of a ramp interval. We can also use other descriptors, such as the duration of a ramp event, to characterize them [7]. There are two ways in which we can do this. One is to consider all time intervals in T to $T + \Delta T$ to form the ramp, and then consider the next interval, $T + \Delta T + 1$, to determine if it is the start of a ramp as well. If so, and the ramp has the same sign as the preceding ramp, then the two sets of intervals can be combined. However, this is not only dependent on the time interval we use for starting the calculation of the ramps, but also overlooks the fact that one of the intervals in T to $T + \Delta T$ could be the start of a ramp of the opposite sign. To address this, we can evaluate each interval to determine if it is the start of a ramp event. Consecutive intervals, with the same sign, that meet the ramp definition can then be considered as the duration of the ramp. We can also extend the last of these intervals by ΔT; however, this again has the drawback that some interval in this ΔT period may not be the start of a ramp event, or may be the start of a different ramp event of the same or opposite sign.

3.3 Counting ramp events

When we attempt to address questions such as, do ramp events occur more frequently during a certain time of day or during certain months of the year, we need to count the number of times a ramp event occurs during the day or month. In the previous section, we described different ways in which we can define if an interval is the start of a ramp event and the duration of the event. When we are given a certain time of day, say early morning, or a certain month, say March, we have several ways in which we can count the ramp events occurring during this time period:

- **Option 1:** We can explicitly count all the intervals which start a ramp event during this period. In a sense, this can be considered as over-counting as we are counting not the events, but the intervals which comprise the event. If there is a large change in generation between two consecutive intervals, it can result in several data points meeting the ramp threshold criterion.

- **Option 2:** Instead of counting all intervals which form a ramp event, which would result in longer ramp events contributing more to the count, we can count only the first interval in a series of consecutive intervals which form a ramp event. Thus, an interval will be considered if it starts a ramp interval, and the previous interval is not the start of a ramp event, or is part of a ramp event of the opposite sign.

- **Option 3:** As a third option, we can do a binary count. In this option, for the time of day analysis, for each day, we would check if a ramp event did or did not occur during that time of day. This count would essentially give us the number of days when there was a ramp event during a specific time period of the day. For the month of the year analysis, in this option, we would count the number of days in each month which had ramp events. This option could be considered as under counting the number of ramps in a time period as many distinct ramps occurring during this period will not be individually counted.

Note that in Options 1 and 3, if a ramp event straddles a time period boundary, it can get counted in two time periods. This is not the case in Option 2, as it only counts the start of distinct ramp events.

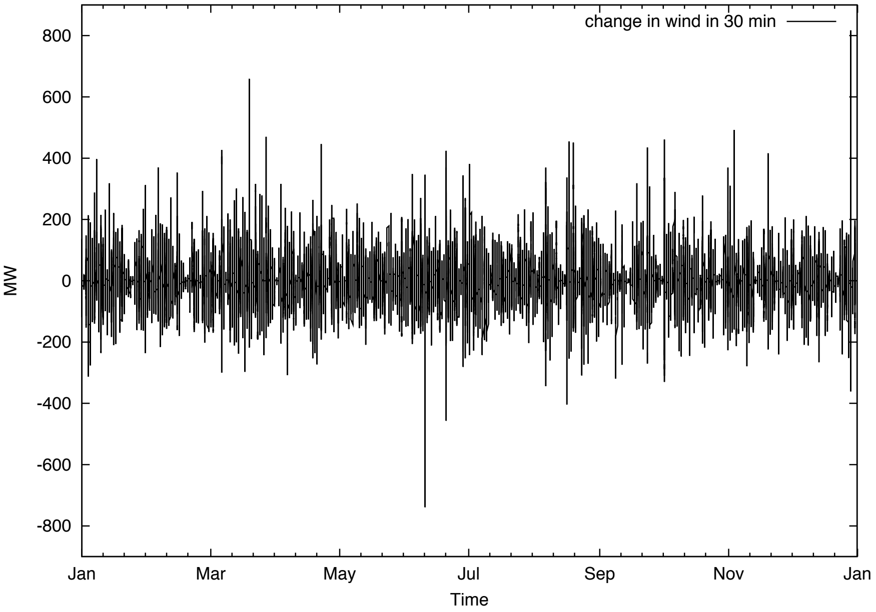


Figure 5: The change in wind energy generated for 30 min intervals (ramp definition 1), for the BPA region for 2008. Based on this, we select two thresholds $Tr_{MW} = 120$ and 210 for our comparison study.

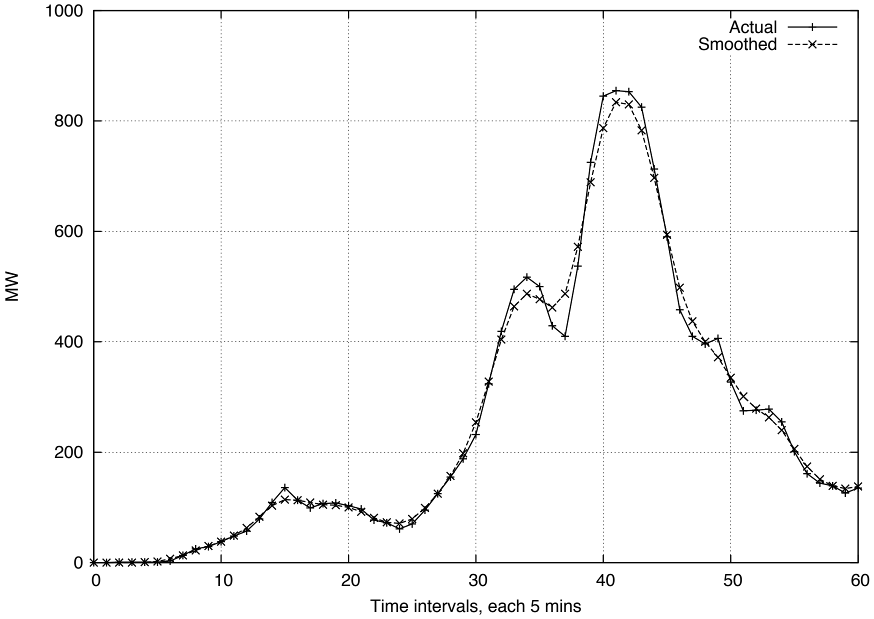
4 Comparison of definitions and options

In Section 3, we considered different ways in which we can process the original data, define ramp events, and count the occurrences in a given time period. Before we extract any statistics on the BPA and SCE data for the years 2007-2009 and 2007-2008, respectively, we need to determine if the statistics are sensitive to our choice of how we define a ramp, how we count them, or if we smooth the data prior to the calculation of the ramps.

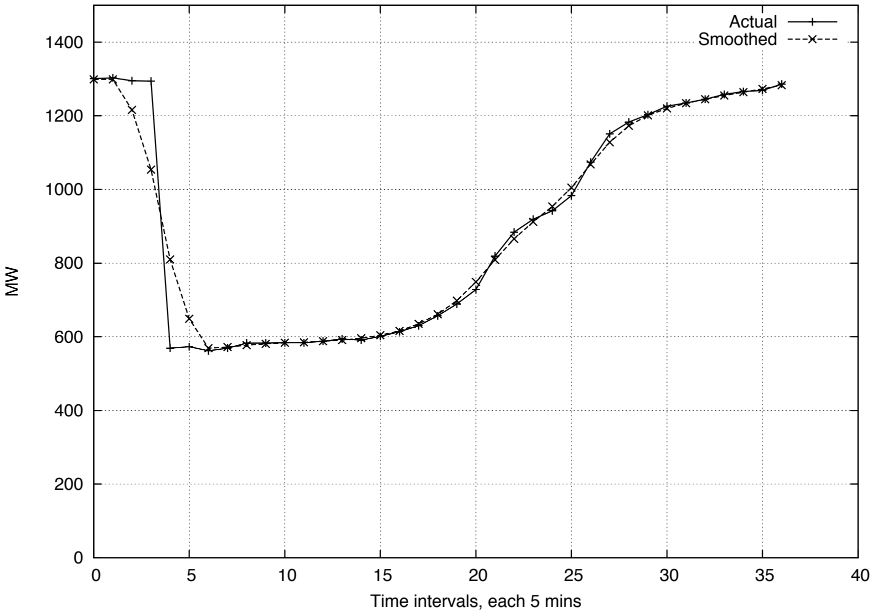
We conduct our study on the effect of different options using BPA data from 2008, with ΔT of 30 mins. Figure 5 shows the change in wind generation (that is, ramp definition 1) over 30 minute intervals for 2008. At each 5 minute time interval, the y-axis is the difference between the generation at that time interval and 30 minutes later. Based on this plot, we consider two thresholds for our comparison study, $Tr_{MW} = 120$, which can be considered as a ramp of low severity, and $Tr_{MW} = 210$, which can be considered as a ramp of moderate severity.

4.1 Effect of smoothing

One of the steps in the pre-processing of the time series data is the reduction of the high frequency components by smoothing using mean or Gaussian filters, or more complex techniques, such as wavelets. This smoothing can be applied more than once to get the desired results. For example, Figure 6(a) shows the effects of smoothing using a simple mean filter, of width 3, applied twice. That is, each application replaced the value at a point by the mean of the values at the point and its two neighbors on either side. This figure is a five hour subset, from noon through 5:00pm, of the time period shown in Figure 4.



(a)



(b)

Figure 6: Effect of smoothing on the choice of ΔT and the Tr_{MW} used in the ramp definition. (a) A five hour subset, from noon through 5:00pm, from Figure 4, illustrating the effects of smoothing. (b) A large drop in generation over a single 5 minute interval on June 11, 2008 in the BPA region. Plot shows generation between noon and 3:00pm.

We observe that in regions where the time series changes gradually, such as the first part of Figure 6(a), the smoothing has little effect. However, if there are high frequency components, such as the period between intervals 30 and 40, the time series is smoothed, making the calculation of the ramps computationally stable. We note that the smoothing does not have a major effect on the large up ramp which is followed by the large down ramp (near interval 42), though it does reduce the height of the peak.

The amount of smoothing applied must take into account the ΔT and the Tr_{MW} used in the definition of the ramp. For example, Figure 6(b) shows the effect of smoothing on a large drop in generation which occurs within 5 minutes, that is, between two consecutive intervals. The smoothing has the effect of changing the drop of 725 MW (from 1294 to 569 MW) to a drop of 244 MW (from 1054 to 810 MW). As a result, if we were to consider 5 minutes as the ΔT in our ramp calculation, a threshold of 250MW would not identify the ramp in the smoothed data. Since each application of the filter considers 3 consecutive intervals and it is applied twice, the smoothing affects the values over 6 intervals. Thus, we should be careful in considering ramp events for ΔT less than 6 intervals, that is, 30 mins. As Table 1 shows, the magnitude of the large drop does get picked up when we consider ΔT of 30 and 60 minutes. A similar effect is seen in Figure 6(a), around interval 35, where a drop of 107 MW (from 517 to 410 MW) over 15 minutes is completely removed in the smoothing (with the smoothed values at the two end points of the interval being 487 MW, with a slight dip to 467 MW in the middle). It may therefore be advisable, while working with smoothed data, to select thresholds slightly smaller than those which would be used with unsmoothed data.

4.2 Comparison of ramp definitions

We next consider the three different definitions of ramp events as described in Section 3.2. We applied the definitions to the smoothed version of BPA data from 2008, where smoothing was done using a simple mean filter, of width 3, applied twice.

We next carefully analyzed the intervals identified as being the start of a ramp period by each of the three definitions. We used two thresholds Tr_{MW} of 120 and 210, which correspond to Tr_{sl} of 20 and 35, respectively, as the data are available at 5 minute intervals. Our analysis indicated the following:

- As expected, definition 2 identifies more ramps than definition 1 as it considers cases where the maximum and minimum in an interval occur at points other than the end points. We found no cases where method 1 identifies a ramp, but method 2 does not.
- Ramps identified by definition 3 could start and/or end an interval later than the ramps identified by the other two definitions. However, since each interval is only 5 minutes, this is not a serious concern.
- A definition may miss identifying a ramp event if it is very near the threshold. So, for a threshold $Tr_{MW} = 120$, an interval with a change in generation of 121 MW would be flagged as the start of a ramp event by definitions 1 and 2, but this might be just below the corresponding threshold for definition 3. This situation occurs in both isolated intervals (where only one interval meets the threshold criterion) and at the start or end of longer ramp events. This behavior is to be expected in any method based on a threshold.

These observations indicate that while definition 2 is preferred over definition 1, there is not much difference among the three methods. As a more detailed example, the plot in Figure 7

Time	Actual	Smoothed	ΔT = 5min	ΔT = 15min	ΔT = 30min	ΔT = 60min
11:00	1205	1211	0	22	66	85
11:05	1207	1211	7	40	71	86
11:10	1215	1218	15	49	66	79
11:15	1226	1233	18	44	54	66
11:20	1252	1251	16	31	39	48
11:25	1279	1267	10	17	27	32
11:30	1279	1277	5	10	19	-83
11:35	1284	1282	2	8	15	-245
11:40	1282	1284	3	10	13	-489
11:45	1289	1287	3	9	12	-650
11:50	1290	1290	4	7	9	-730
11:55	1294	1294	2	3	5	-730
12:00	1298	1296	1	3	-83	-730
12:05	1302	1297	0	2	-245	-730
12:10	1288	1297	2	2	-489	-730
12:15	1303	1299	0	-83	-650	-730
12:20	1301	1299	0	-245	-730	-730
12:25	1303	1299	-83	-489	-730	-730
12:30	1295	1216	-162	-567	-647	-647
12:35	1294	1054	-244	-485	-485	-485
12:40	569	810	-161	-241	-241	-241
12:45	573	649	-80	-80	-80	-80
12:50	562	569	3	12	19	92
12:55	569	572	5	12	19	126
13:00	583	577	4	8	19	172
13:05	583	581	3	7	23	228
13:10	584	584	1	7	32	282
13:15	584	585	3	11	50	327
13:20	588	588	3	16	73	366
13:25	594	591	5	25	107	414
13:30	591	596	8	39	153	472
13:35	601	604	12	57	205	524
13:40	614	616	19	82	250	557
13:45	630	635	26	114	277	566
13:50	657	661	37	148	293	559
13:55	689	698	51	168	307	536
14:00	728	749	60	163	319	496

Table 1: Effect of smoothing on the ramp in Figure 6(b), showing the values of the actual generation in MW, the smoothed generation in MW, and the change in the smoothed generation using definition 2 over 5, 15, 30, and 60 minutes.

shows the actual and smoothed generation in a 2 hour period between 7:00am and 9:00am on October 2, 2008. Figure 8 shows the intervals identified as a ramp (indicated by a 1 or -1 for positive and negative ramps, respectively) by the three definitions for this 2 hour period. The differences among the definitions are at 7:05, 7:35, 8:40, and 8:50am. At 8:40 and 8:50am, definition 2 identifies ramps as the change in generation is -121 and -122 MW, respectively. In contrast, definition 1 identifies the change in generation as -116 for both times, thus just missing the threshold.

4.3 Comparison of count options

We next consider the effect of using different options for counting the ramp events in any given period (see Section 3.3). We consider the case where we are interested in evaluating the occurrence of ramp events based on the time of day. We consider each day to be divided into four parts: early and late morning, and early and late afternoon, representing the times from midnight-6:00am, 6:00am-noon, noon-6:00pm, and 6:00pm - midnight, respectively. Tables 2 and 3 illustrate the counts of ramp events using the three different options for the two thresholds. For completeness, we have included the results for each of the three ramp definitions; these results confirm the observations from Section 4.2.

As expected, Tables 2 and 3 indicate that the ramp count using option 1 is much greater than either options 2 or 3 as we are counting all the intervals which form the ramp. Option 3, being a binary count, gives the smallest count among the three options. However, what is most interesting in the results presented in Tables 2 and 3 is that the qualitative analysis of the occurrence of ramp events is the same, regardless of the ramp definition or the counting option. In particular, we observe that for the BPA region, for $\Delta T = 30$ minutes, the data from 2008 indicates the following:

- The total number of positive ramps is greater than the total number of negative ramps. For a given time period, the count of positive ramps is greater than negative ones, except for early morning, when small negative ramps (Tr_{MW}=120) are more frequent.
- For smaller ramps (Tr_{MW}=120), positive ramps tend to occur in early afternoon, while negative ramps are more frequent in early morning and late evening.
- For moderate ramps (Tr_{MW}=210), positive ramps tend to occur in early afternoon, while negative ramps are more frequent in early afternoon and late evening, but occur less frequently in early or late morning.

NOTE: As the analysis results do not depend on the ramp definition or the way in which we count the occurrences of ramp events, in the rest of this report, we will consider ramp definition 2, which considers the maximum and minimum generation in a time period, and counting option 2, where a contiguous set of intervals, each of which starts a ramp of the same sign, is counted as a single ramp event.

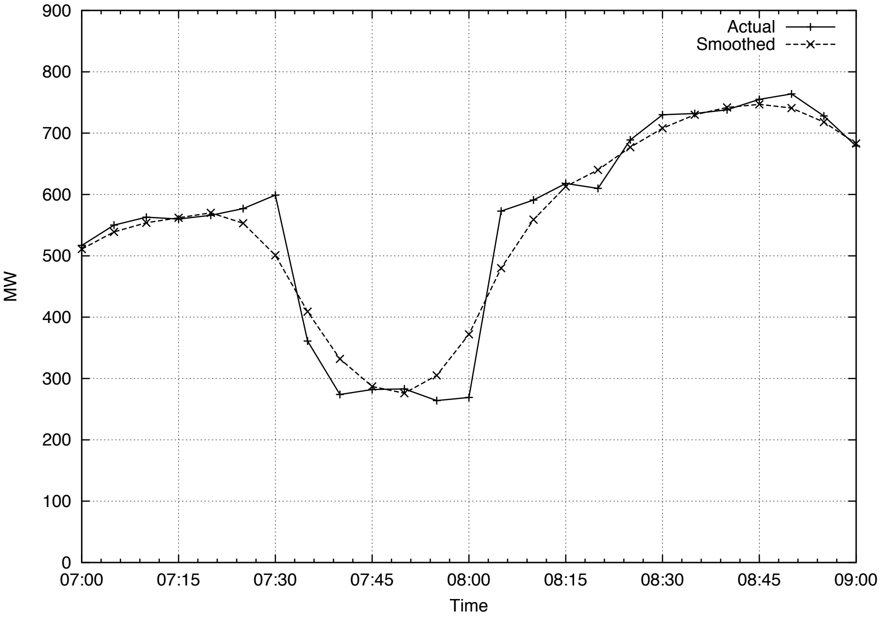


Figure 7: The actual and smoothed generation for the time period 7:00-9:00am for October 2, 2008, BPA region.

Time	Defn 1	Defn 2	Defn 3	Time	Defn 1	Defn 2	Defn 3
7:00	0	0	0	8:00	1	1	1
7:05	-1	-1	0	8:05	1	1	1
7:10	-1	-1	-1	8:10	1	1	1
7:15	-1	-1	-1	8:15	1	1	1
7:20	-1	-1	-1	8:20	0	0	0
7:25	-1	-1	-1	8:25	0	0	0
7:30	-1	-1	-1	8:30	0	0	0
7:35	0	1	0	8:35	0	0	0
7:40	1	1	1	8:40	0	-1	0
7:45	1	1	1	8:45	-1	-1	-1
7:50	1	1	1	8:50	0	-1	-1
7:55	1	1	1	8:55	0	0	0

Figure 8: The ramp intervals identified by the three definitions during the time period 7:00-9:00am on October 2, 2008 (Figure 7). The values of 0, 1, and -1 indicate no ramp, a positive ramp and a negative ramp, respectively. The threshold Tr_{MW} is set to 120, Tr_{sl} is 20 MW over 5 minutes, and ΔT is 30 minutes. Note the differences at 7:05, 7:35, 8:40, and 8:50am.

Ramp	Definition 1			Definition 2			Definition 3		
time/sign	Opt 1	Opt 2	Opt 3	Opt 1	Opt 2	Opt 3	Opt 1	Opt 2	Opt 3
Early am/pos	332	70	60	338	70	60	330	67	57
Late am/pos	439	85	66	449	85	66	434	79	61
Early pm/pos	972	152	108	990	153	108	955	148	106
Late pm/pos	623	106	85	638	106	85	604	103	81
Early am/neg	490	105	94	496	105	94	478	99	92
Late am/neg	284	58	53	292	58	53	279	56	52
Early pm/neg	351	74	61	368	74	61	345	72	59
Late pm/neg	567	113	92	583	113	92	562	110	93
Total pos	2366	413	319	2415	414	319	2323	397	305
Total neg	1692	350	300	1739	350	300	1664	337	296

Table 2: Comparison of the different ramp definitions and counting options for BPA 2008 data, with $Tr_{MW} = 120$ and $\Delta T = 30$ mins.

Ramp	Definition 1			Definition 2			Definition 3		
time/sign	Opt 1	Opt 2	Opt 3	Opt 1	Opt 2	Opt 3	Opt 1	Opt 2	Opt 3
Early am/pos	43	5	5	44	5	5	42	6	6
Late am/pos	59	10	9	59	10	9	58	10	9
Early pm/pos	144	33	30	147	33	30	140	31	29
Late pm/pos	94	18	16	95	18	16	90	16	16
Early am/neg	14	5	5	14	5	5	10	3	3
Late am/neg	14	4	4	15	4	4	12	4	4
Early pm/neg	56	13	13	57	13	13	51	12	12
Late pm/neg	64	15	15	66	15	15	65	15	15
Total pos	340	66	60	345	66	60	330	63	60
Total neg	148	37	37	152	37	37	138	34	34

Table 3: Comparison of the different ramp definitions and counting options for BPA 2008 data, with $Tr_{MW} = 210$ and $\Delta T = 30$ mins.

5 Statistics and observations

We next describe the various statistics obtained for the ramp events for the Tehachapi Pass region for 2007-2008 and the Columbia Basin region for the years 2007-2009, followed by our observations on these statistics. Since the two regions are distinct, we report the statistics for each separately. In terms of the peak wind generation, the Tehachapi Pass data remains constant over the two years, while the Columbia Basin data increases rapidly from 2007 through 2009. This gives us an opportunity to understand the results of our analysis under two scenarios - one, where the constant peak generation enables us to conduct the analysis without the added complications due to increased generation, and the second, where the increased generation allows us to understand how the statistics will change in the future as wind energy forms a greater part of the resource mix at a utility.

All tables and plots for this section appear in Appendices A and B for the Columbia Basin (BPA) and Tehachapi Pass (SCE) regions, respectively.

A note of caution: the results presented, and the conclusions drawn, are valid for the wind generation for specific years, in the specific region being analyzed. There are many factors which influence the total wind generation in a region; a similar analysis conducted on data from a different region, or the same region but in a year with a very different climate pattern, may not yield similar results or conclusions.

5.1 Statistics for the BPA region, 2007-2009

Our analysis of the time series of wind generation data for the Columbia Basin (BPA) region used the original data smoothed with two applications of a mean filter of size 3. Figure 9 shows that the actual wind power generation increased from 800 MW in early 2007 to over 1000 MW in late 2007. The generation further increased to 1500 MW in 2008 and nearly 2500 MW in 2009. This is the result of both an increase in the number of turbines and improved efficiency of the turbines. This gives us an opportunity to see how the occurrence of ramp events changes with increasing generation. Also, the split of the time series into the three years is somewhat artificial as it is really a continuous time series over three years.

5.1.1 Distributions of change in wind generation

Figures 10 - 12 show the change in wind generation using ramp definition 2, over 15 minute, 30 minute, and 60 minute time periods, respectively, for each of the three years. A more quantitative representation of these figures is provided in Tables 4 - 6. The histograms count the number of intervals (each 5 minutes long) that start a change in generation of a given magnitude for the ΔT being considered, that is, we are using count option 1 (see Section 3.3). These tables and figures give us an idea of how frequently we see changes of different magnitudes.

Note that if there is one interval in a given ΔT period with a large change, then, it will result in many consecutive intervals which "start" a large change. For example, if the generation is 1000 MW at times T, T+1, T+2, and drops to 500 MW at times T+3, T+4, and T+5, then, if we consider 15 minute changes in generation, each of the intervals, T, T+1, and T+2 will have a 500 MW drop. This fact is illustrated in Table 1, where a single large drop of 725 MW in actual generation during one 5 minute interval in June 2008, appears several times when 60 minute changes are considered.

We make several observations based on the tables and figures:

- For a given year, most of the changes in generation are of small magnitude (< 100 MW). As the magnitude of the change increases, the number of occurrences goes down. Large changes in magnitude, of either sign, are possible, that is, severe ramps can be either positive or negative ramps. As expected, the larger the ΔT considered, the more frequent the changes with larger magnitude.
- As the wind power generation increases from 2007 to 2009, the maximum change in generation, both positive and negative, increases as well. For example, for $\Delta T = 15$ and 30 minutes, there are no ramps greater than 400MW in 2007, but in 2009, 13 such ramps occur for $\Delta T = 15$ minutes and 167 ramps for $\Delta T = 30$ minutes.
- In addition, with increased generation, larger changes become more common than before. For example, for $\Delta T = 60$ minutes, in 2007, 92.6% of the intervals have a small change in generation of less than 100MW in magnitude, compared with 69.4% in 2009.
- When ramps of very large magnitude are considered (greater than 200MW in 2007, and greater than 400MW in 2008 and 2009), the positive ramps tend to outnumber the negative ones. However, as the generation increases and the previously large magnitude ramps become more common, then the negative ramps become equally, if not more, frequent. See, for example, the results for $\Delta T = 60$ minutes for the three years.

Table 7 lists the largest positive and negative ramps for the three intervals in each of the three years. While the maximum may be an outlier in some years, such as 2008, in other years there are several days when ramps near the maximum occur; see for example, the 2009 data in Figures 11 and 12. These results confirm that, at least for the BPA region, for the specific years considered, as the total generation increases, the magnitude and occurrences of the largest ramps also increase.

5.1.2 Time-of-day occurrence of ramp events

Next, we consider the time of day when the ramp events occur. Focusing on the 30 and 60 minute time intervals, we select three thresholds for each to identify ramps of low, moderate, and high severity. We consider each day to be divided into four parts: early and late morning, and early and late afternoon, representing the times from midnight-6:00am, 6:00am-noon, noon-6:00pm, and 6:00pm - midnight, respectively. Then, considering the changes in the wind generation for the two time intervals, we collect statistics on when ramp events exceeding a certain magnitude occurred. We focused on the data from 2008 and 2009 as the greater generation in these years resulted in a sufficient number of ramp events to make any statistics meaningful; our results are summarized in Tables 8 - 9.

These tables indicate that for the Columbia Basin region, both positive and negative ramps of any magnitude can occur at any time of the day, though positive ramps tend to occur more frequently than negative ramps. Very severe ramps (that is, the high threshold cases) can be of either sign, though the positive ones tend to outnumber the negative ones. Positive ramps tend to occur in the early afternoon, while negative ramps are more frequent in the early morning and late evening. Also, certain observations made for the 2008 data, such as the relatively infrequent occurrence of moderate to large downward ramps during early or late morning hours, no longer hold for the 2009 data.

Comparing the 2008 and 2009 data, we find that the increased wind generation leads to more ramp events, which is expected, though it is unclear if all the increase can be attributed to the increased generation.

5.1.3 Month of the year occurrences

Finally, we analyze the ramp events to determine if there are any monthly variations. Tables 10 and 11 show the number of ramp events in a month of low, moderate, and high severity. Since the division of days into months is somewhat artificial (for example, a very active period for ramp events may straddle two months, but neither may individually show a relatively high incidence of ramp events), we need to interpret these results with care, especially given the sparsity of data for the moderate and high ramps.

We observe that the probability of ramp events in certain months, for example, March, June, and August tends to be high for both 2008 anbd 2009. However, certain months, such as as May, which has relatively fewer ramps in 2008, has far more ramps in 2009, several of them of high severity, while November has moderate ramp activity in 2008 and high activity in 2009.

5.2 Statistics for the SCE region, 2007-2008

Our analysis of the time series wind generation data for the Tehachapi Pass (SCE) region used the original data without any smoothing. As the data are available at 15 min intervals, and we are interested in ramps over 30 and 60 minutes, any smoothing could have a large effect on the magnitudes of the ramps. Figure 13 shows the actual wind power generation for 2007 and 2008. We observe that, unlike the BPA region, the peak generation is roughly constant at 500MW. This gives us an opportunity to obtain statistics on the frequency of ramp events without being influenced by the effects of increasing generation. As before, we observe that the split of the time series into the two years is somewhat artificial as it is really a continuous time series over these years.

5.2.1 Distributions of change in wind generation

Figures 14 - 16 show the change in wind generation using ramp definition 2, over 15 minute, 30 minute, and 60 minutes time periods, respectively, for the two years. A more quantitative representation of the figures is provided in Tables 12 - 13. The histograms count the number of intervals (each 15 minutes long) that start a ramp of a given magnitude for the ΔT being considered. As in the case of the BPA data, if there is one interval in a given ΔT period, with a large ramp, then, it will result in many consecutive intervals which “start” a large ramp.

Table 14 lists the largest positive and negative ramps for the three intervals in the two years. We make several observations based on the tables and figures:

- When we consider very small changes in the generation (less than 50MW), for $\Delta T = 15$ minutes, there are more positive changes than negative ones, though as ΔT increases, the numbers are more balanced.
- For larger changes in the generation (greater than 100 MW), in 2007, the positive changes outnumbered the negative ones, though in 2008, they were roughly equal.
- Large negative ramps can be as severe as large positive ramps.

5.2.2 Time-of-day occurrence of ramp events

Next, we consider the time of day when the ramp events occur. Focusing on the 30 and 60 minute time intervals, we select two thresholds for each to identify ramps of low and high severity. Unlike the BPA data, the peak generation in Tehachapi Pass is not very high, and the range of magnitude of the ramps is relatively small. Hence, we consider only two thresholds of 100 MW and 150 MW for the 30 minute ramps and 150 MW and 200 MW for the 60 minute ramps. As before, we consider each day to be divided into four parts: early and late morning, and early and late afternoon, representing the times from midnight-6:00am, 6:00am-noon, noon-6:00pm, and 6:00pm - midnight, respectively. Then, considering the changes in the wind generation for the two time intervals, we collect statistics on when ramp events exceeding a certain magnitude occurred. Our results for 2007 and 2008 are summarized in Tables 15-16.

These tables indicate that both positive and negative ramps of any magnitude can occur at any time of the day. The total number of positive ramps is slightly greater than the total number of negative ramps. However, since the total generation in the Tehachapi Pass is relatively small, there are not enough ramp events to draw any strong conclusions about time-of-day occurrence of these events.

5.2.3 Month of the year occurrences

Finally, we analyze the ramp events to determine if there are any monthly variations. Tables 17 and 18 show the number of times a month when ramps with low and high severity occur. Since the total number of ramps for the Tehachapi Pass region is relatively small compared to the Columbia Basin, it is harder to determine if there is a higher probability of ramp events in certain months. However, the tables do indicate that ramps tend to be less frequent in the summer months (May through September) and more frequent during the winter months (October through April).

6 Conclusions

In this report, we have shown that simple statistical analysis of wind generation can provide insights into ramp events such as distributions of their severity levels, their time of occurrence during the day, and their occurrence by month. We conducted our analysis using data from two regions - the Columbia Basin, where the installed wind power has been steadily increasing from 2007 to 2009, and the Tehachapi Pass region, where the generation has been constant. While the results of such analysis will be different for different regions, and depend on the location of the wind farm and the amount of wind generation, it can none-the-less provide grid operators additional information they can use in balancing the load.

We also considered different ways of defining a ramp event and counting them; a careful and detained analysis indicated that there were no major differences among the definitions or counting options. Instead, the statistics obtained depended on utility-specific factors, such as the magnitude of the ramp and the time interval over which the change occurred. These factors are driven by the challenges faced by schedulers and operators in keeping the load and generation balanced. They can change over the years, varying with climate effects as well as the resource mix at a utility.

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A Statistics for the BPA region, 2007-2009

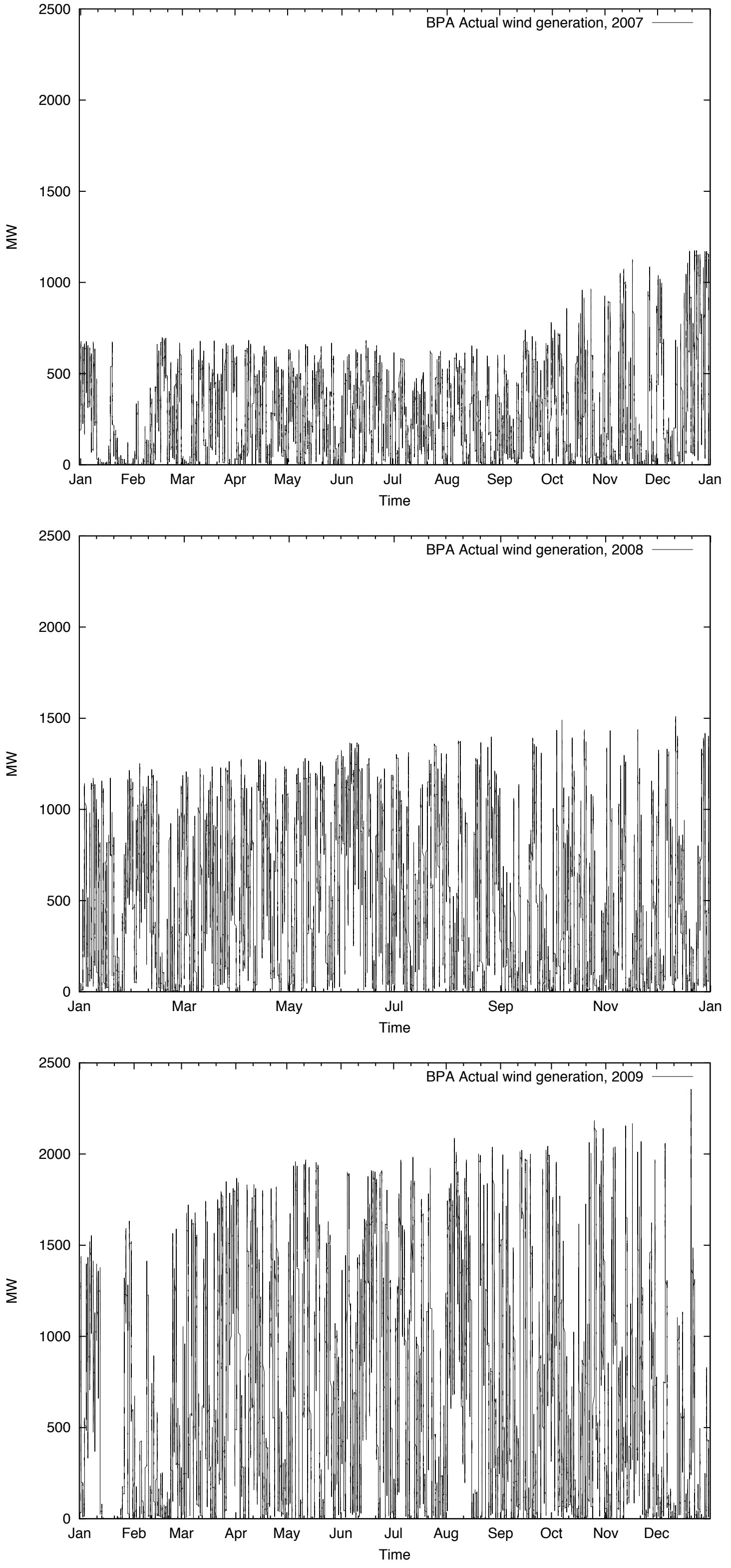


Figure 9: BPA wind generation for, top to bottom, 2007, 2008, and 2009. Same scale used for all plots to show the increase in total generation over the years.

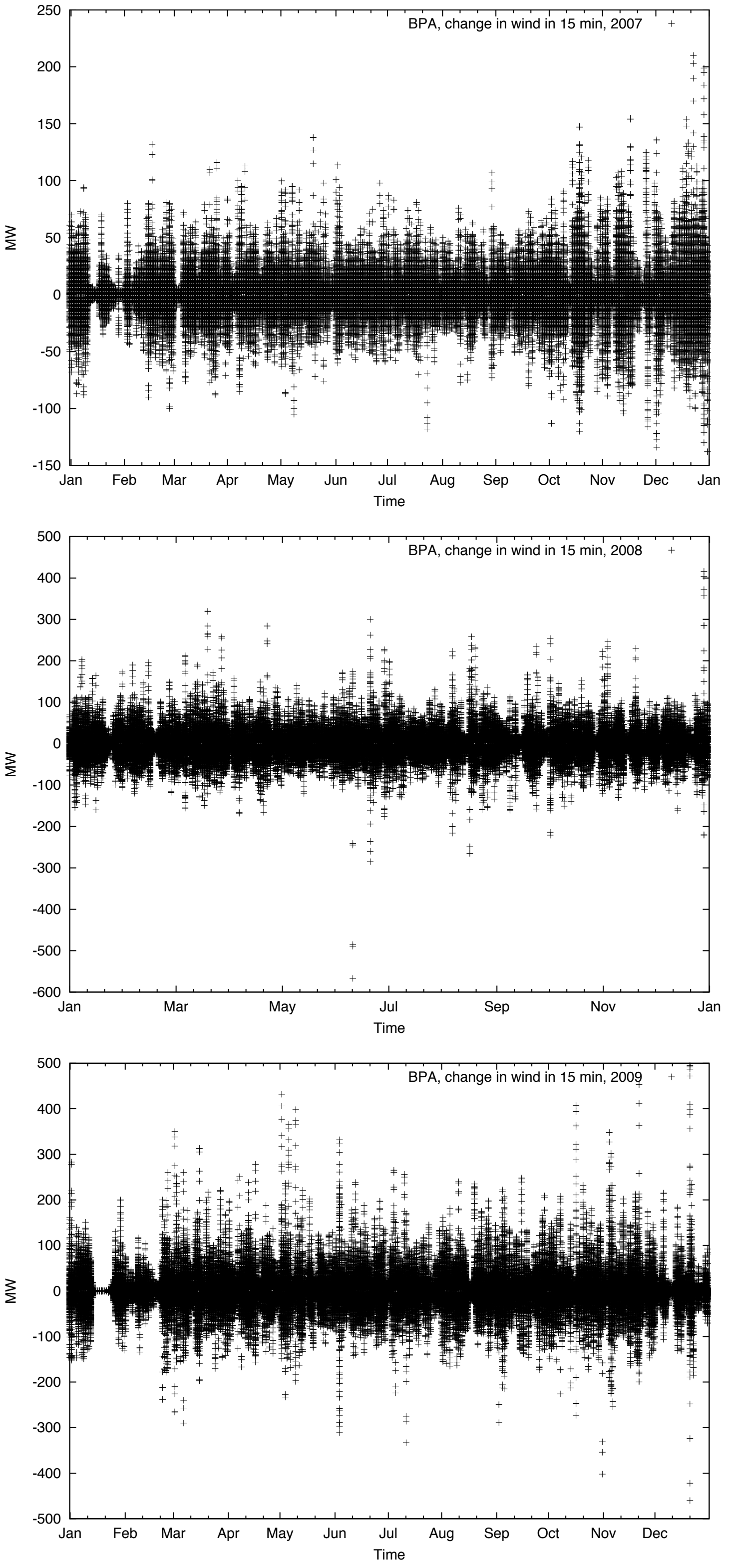


Figure 10: BPA, 15 minute change in wind generation (ramp definition 2) for, top to bottom, 2007, 2008, and 2009. Different scales are used for the plots.

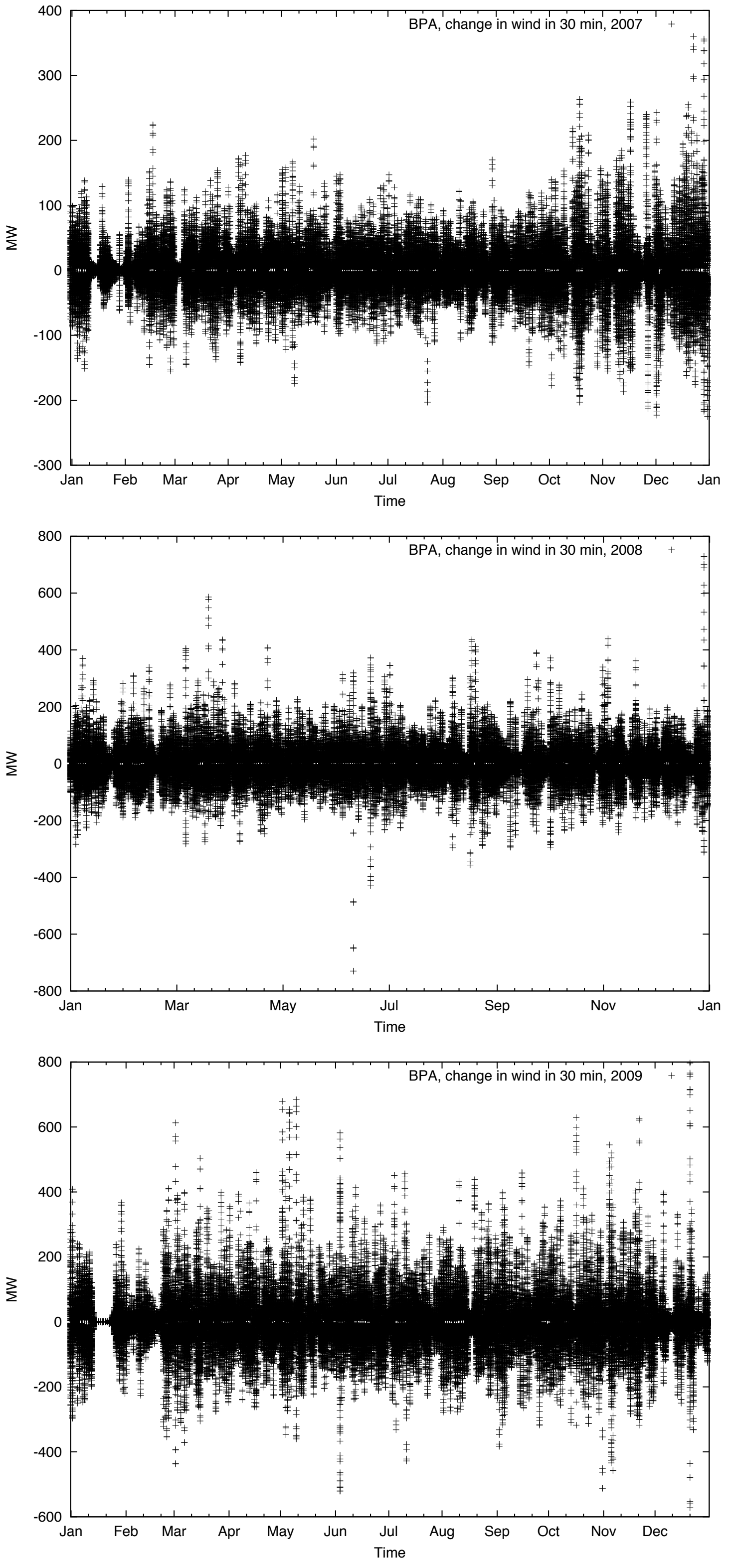


Figure 11: BPA, 30 minute change in wind generation (ramp definition 2) for, top to bottom, 2007, 2008, and 2009. Different scales are used for the plots.

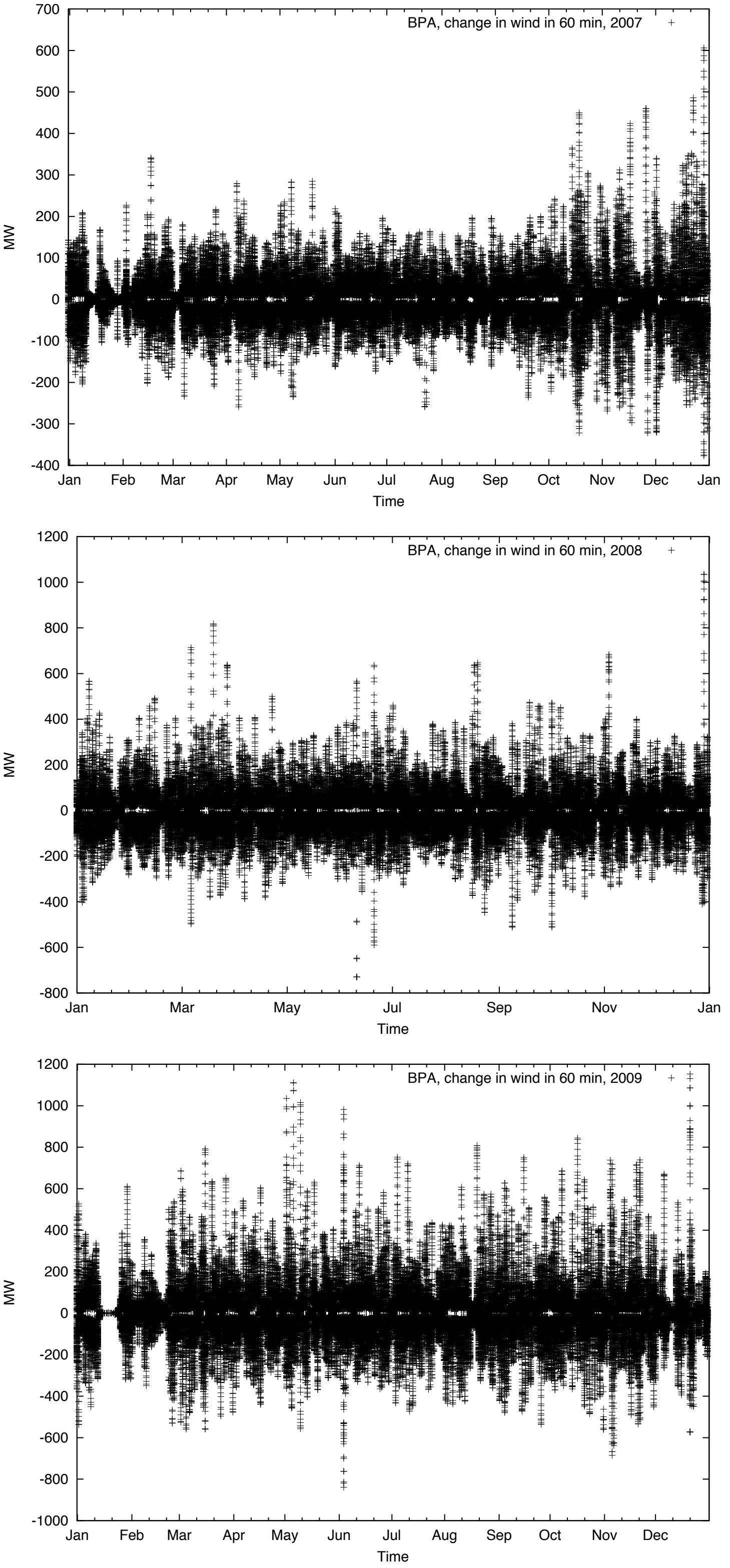


Figure 12: BPA, 60 minute change in wind generation (ramp definition 2) for, top to bottom, 2007, 2008, and 2009. Different scales are used for the plots.

$\lvert\Delta MW\rvert$	15 minute		30 minute		60 minute	
	pos	neg	pos	neg	pos	neg
$> 0MW$, $< 100MW$	55716	49202	53200	50141	49116	48195
$\geq 100MW$, $< 200MW$	116	49	1010	635	3668	3217
$\geq 200MW$, $< 400MW$	2	0	83	19	555	299
$\geq 400MW$	0	0	0	0	44	0

Table 4: Distribution of changes in wind generation (definition 2) for different values of ΔT for 2007. Changes of magnitude zero are counted in the positive column in the first row.

$\lvert\Delta MW\rvert$	15 minute		30 minute		60 minute	
	pos	neg	pos	neg	pos	neg
$> 0MW$, $< 100MW$	53185	51243	48886	49312	40655	41250
$\geq 100MW$, $< 200MW$	557	315	3491	3069	8850	10002
$\geq 200MW$, $< 400MW$	55	13	387	192	2493	1853
$\geq 400MW$	2	3	31	8	220	59

Table 5: Distribution of changes in wind generation (definition 2) for different values of ΔT for 2008. Changes of magnitude zero are counted in the positive column in the first row.

$\lvert\Delta MW\rvert$	15 minute		30 minute		60 minute	
	pos	neg	pos	neg	pos	neg
$> 0MW$, $< 100MW$	52523	49632	46430	45493	37067	35840
$\geq 100MW$, $< 200MW$	1587	1063	5283	5531	9811	11598
$\geq 200MW$, $< 400MW$	184	59	1374	792	4719	4609
$\geq 400MW$	10	3	133	34	1077	367

Table 6: Distribution of changes in wind generation (definition 2) for different values of ΔT for 2009. Changes of magnitude zero are counted in the positive column in the first row.

Year	15 minute		30 minute		60 minute	
	pos	neg	pos	neg	pos	neg
2007	210	-138	360	-225	606	-377
2008	416	-567	729	-730	1035	-730
2009	495	-460	797	-572	1153	-839

Table 7: Maximum (positive and negative) changes in wind generation (definition 2) for different values of ΔT for 2007-2009.

Ramp time/sign	2008 Thresholds			2009 Thresholds		
	120	210	300	120	210	300
Early am/pos	70	5	3	109	29	7
Late am/pos	85	10	5	141	43	13
Early pm/pos	153	33	7	204	77	36
Late pm/pos	106	18	9	165	50	18
Early am/neg	105	5	0	194	38	6
Late am/neg	58	4	0	125	29	5
Early pm/neg	74	13	3	103	30	8
Late pm/neg	113	15	1	220	50	10
Total/pos	414	66	24	619	199	74
Total/neg	350	37	4	642	147	29

Table 8: Time of day occurrences of 30 min ramps at low, moderate, and high thresholds for 2008 and 2009. The number indicates the number of times a positive or negative ramp event of magnitude greater than the threshold starts in that time period of the day.

Ramp time/sign	2008 Thresholds			2009 Thresholds		
	240	420	600	240	420	600
Early am/pos	18	2	1	50	14	5
Late am/pos	38	4	2	74	19	4
Early pm/pos	76	8	2	131	47	17
Late pm/pos	39	7	3	72	20	9
Early am/neg	36	0	0	88	10	1
Late am/neg	18	1	1	60	7	0
Early pm/neg	28	2	0	46	11	2
Late pm/neg	40	3	0	104	14	1
Total/pos	171	21	8	327	100	35
Total/neg	122	6	1	298	42	4

Table 9: Time of day occurrences of 60 min ramps at low, moderate, and high thresholds for 2008 and 2009. The number indicates the number of times a positive or negative ramp event of magnitude greater than the threshold starts in that time period of the day.

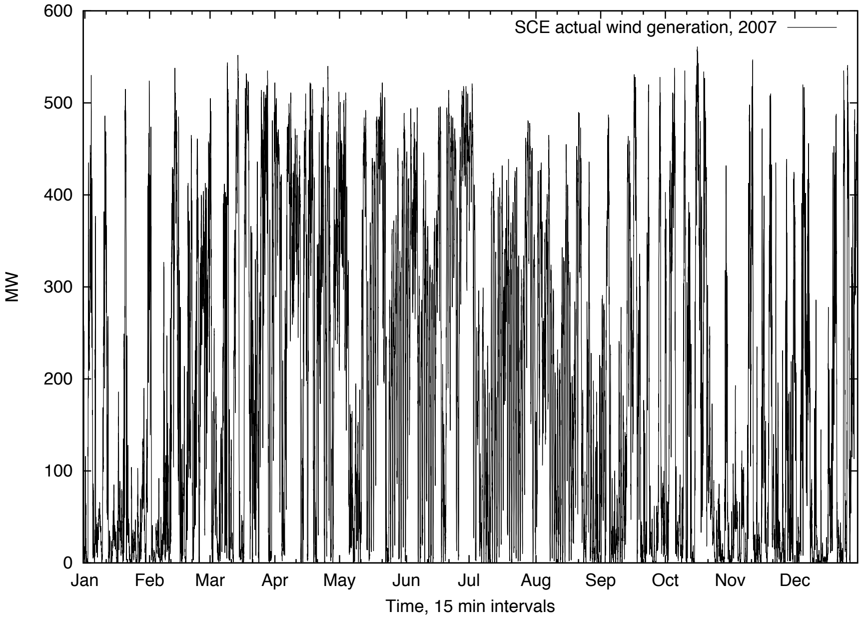
			J	F	M	A	M	J	J	A	S	O	N	D
2008	Tr=120	pos	40	34	51	37	23	42	20	50	18	39	29	31
		neg	32	26	38	27	18	39	23	35	22	32	33	25
		tot	72	60	89	64	41	81	43	85	40	71	62	56
	Tr=210	pos	7	4	12	4	1	12	3	7	4	4	7	1
		neg	3	0	3	3	0	4	1	8	4	5	2	4
		tot	10	4	15	7	1	16	4	15	8	9	9	5
	Tr=300	pos	1	2	3	1	0	5	1	4	1	1	4	1
		neg	0	0	0	0	0	2	0	1	0	0	0	1
		tot	1	2	3	1	0	7	1	5	1	1	4	1
2009	Tr=120	pos	50	28	71	48	54	55	44	60	53	56	68	32
		neg	44	21	69	49	62	58	35	65	60	64	84	31
		tot	94	49	140	97	116	113	79	125	113	120	152	63
	Tr=210	pos	10	6	19	18	18	18	9	19	18	24	31	9
		neg	10	11	16	9	12	8	7	11	19	14	22	8
		tot	20	17	35	27	30	26	16	30	37	38	53	17
	Tr=300	pos	2	2	9	4	8	9	4	4	6	7	14	5
		neg	0	2	4	0	2	3	2	0	4	3	6	3
		tot	2	4	13	4	10	12	6	4	10	10	20	8

Table 10: Monthly occurrences of 30min ramps at low, moderate, and high thresholds for 2008 and 2009. The number indicates the number of times a positive or negative ramp event of magnitude greater than the threshold occurs in that month.

			J	F	M	A	M	J	J	A	S	O	N	D
2008	Tr=240	pos	15	14	21	15	10	20	10	18	9	10	13	16
		neg	11	8	13	10	5	16	6	15	8	10	10	10
		tot	26	22	34	25	15	36	16	33	17	20	23	26
	Tr=420	pos	2	2	3	1	0	3	1	2	3	2	1	1
		neg	0	0	1	0	0	2	0	1	1	1	0	0
		tot	2	2	4	1	0	5	1	3	4	3	1	1
	Tr=600	pos	0	0	3	0	0	1	0	2	0	0	1	1
		neg	0	0	0	0	0	1	0	0	0	0	0	0
		tot	0	0	3	0	0	2	0	2	0	0	1	1
2009	Tr=240	pos	23	14	36	28	30	34	22	32	28	32	36	12
		neg	19	11	33	18	27	28	19	32	27	30	40	14
		tot	42	25	69	46	57	62	41	64	55	62	76	26
	Tr=420	pos	3	3	10	6	8	12	6	7	11	11	18	5
		neg	2	1	8	3	2	2	3	3	5	2	8	3
		tot	5	4	18	9	10	14	9	10	16	13	26	8
	Tr=600	pos	1	0	4	1	6	4	2	2	2	4	6	3
		neg	0	0	0	0	0	2	0	0	0	0	2	0
		tot	1	0	4	1	6	6	2	2	2	4	8	3

Table 11: Monthly occurrences of 60min ramps at low, moderate, and high thresholds for 2008 and 2009. The number indicates the number of times a positive or negative ramp event of magnitude greater than the threshold occurs in that month.

B Statistics for the SCE region, 2007-2008



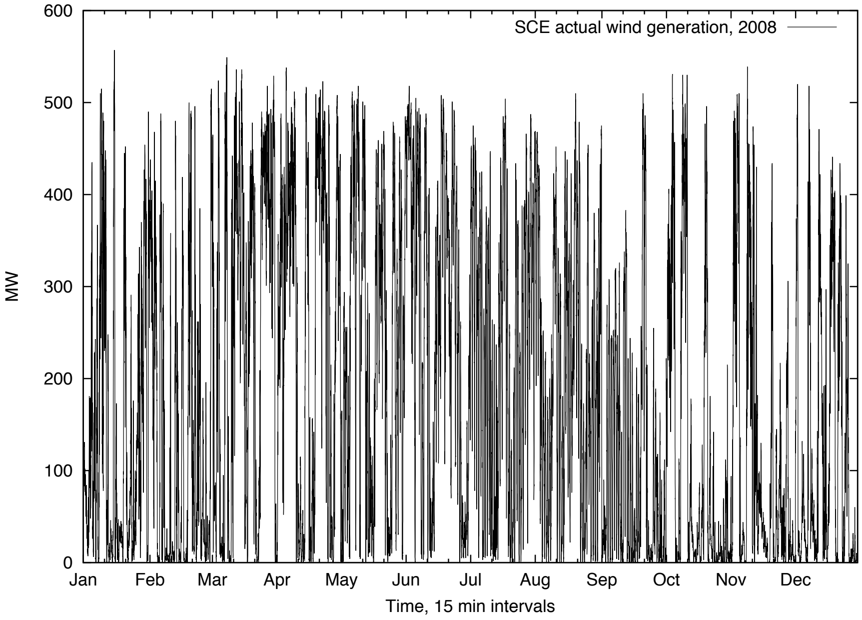
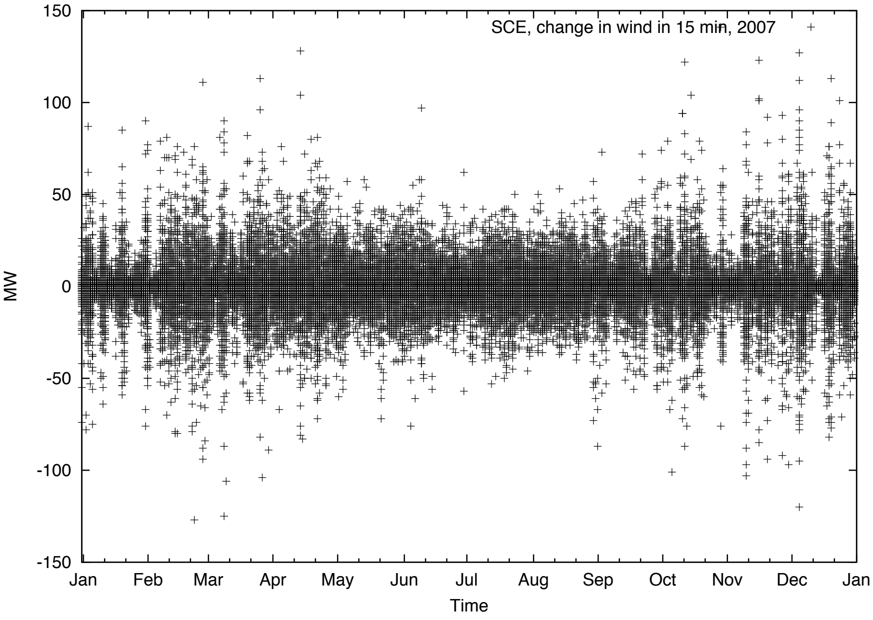


Figure 13: SCE wind generation for, 2007 (top) and 2008 (bottom). Same scale used for both plots.



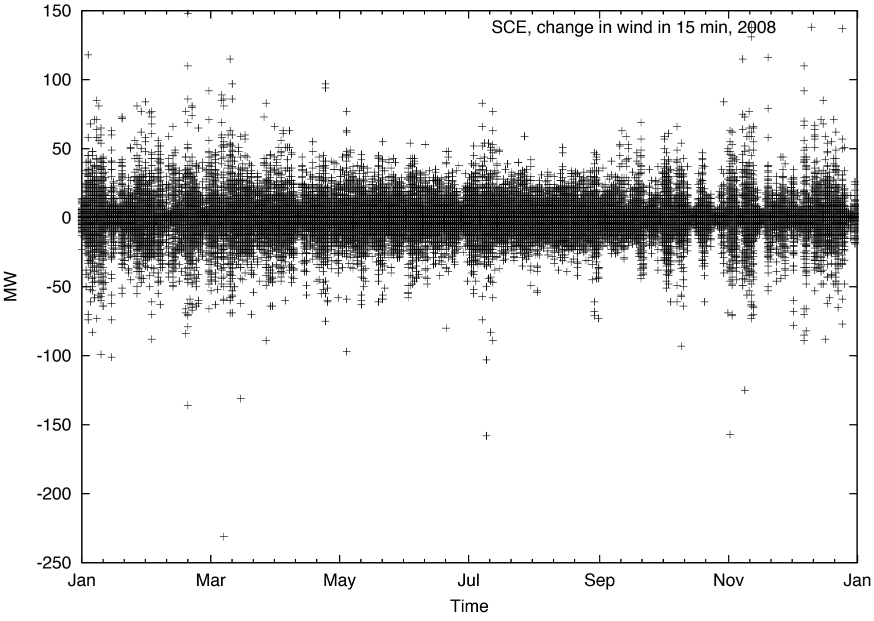


Figure 14: SCE, 15 minute change in wind generation (ramp definition 2) for, 2007 (top) and 2008 (bottom). Different scales are used for the plots.

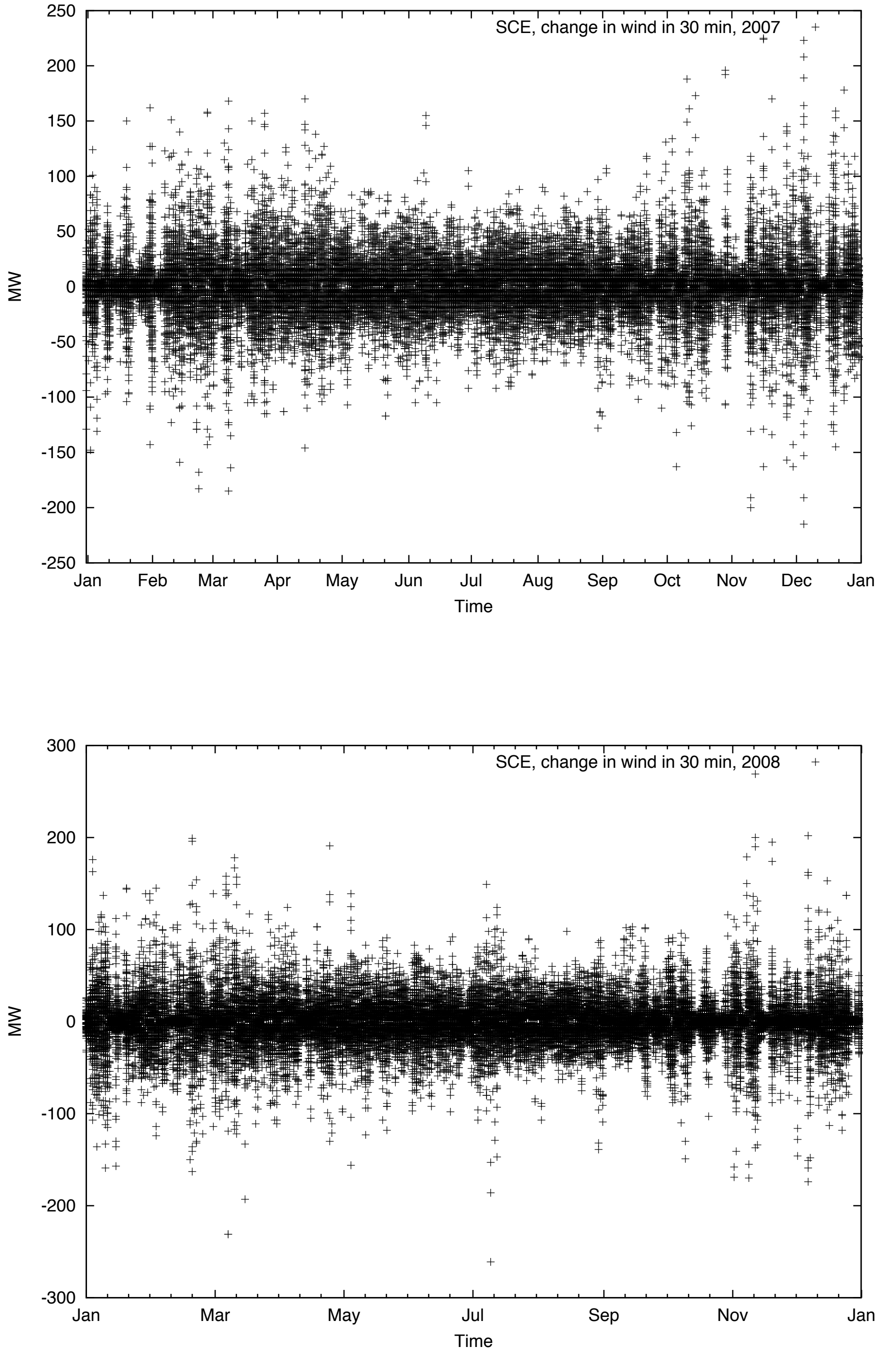
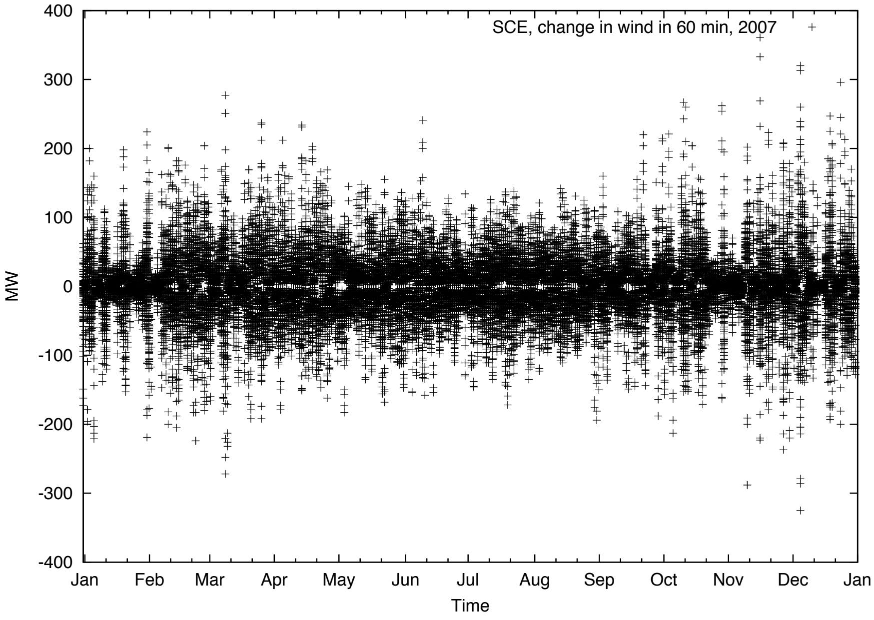


Figure 15: BPA, 30 minute change in wind generation (ramp definition 2) for, 2007 (top) and 2008 (bottom). Different scales are used for the plots.



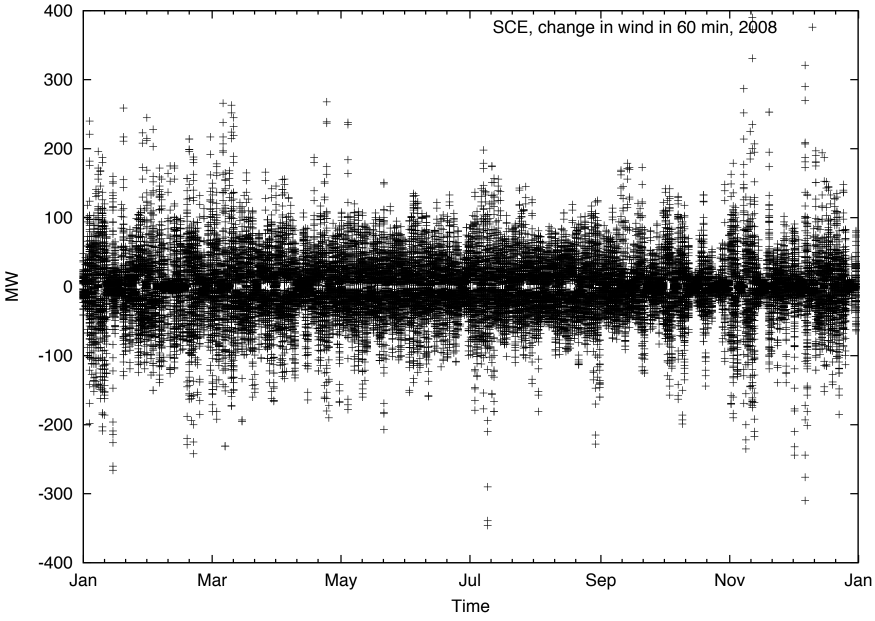


Figure 16: SCE, 60 minute change in wind generation (ramp definition 2) for, 2007 (top) and 2008 (bottom). Same scales are used for the plots.

$\lvert\Delta MW\rvert$	15 minute		30 minute		60 minute	
	pos	neg	pos	neg	pos	neg
$> 0MW, < 50MW$	18810	15798	16665	15938	13853	13722
$\geq 50MW, < 100MW$	202	202	1105	1077	2915	2921
$\geq 100MW, < 200MW$	14	7	143	99	808	720
$\geq 200MW$	0	0	4	2	62	32

Table 12: Distribution of changes in wind generation (definition 2) for different values of ΔT for 2007. Changes of magnitude zero are counted in the positive column in the first row.

$\lvert\Delta MW\rvert$	15 minute		30 minute		60 minute	
	pos	neg	pos	neg	pos	neg
$> 0MW, < 50MW$	19224	15561	17146	15952	14265	14107
$\geq 50MW, < 100MW$	169	157	936	885	2853	2587
$\geq 100MW, < 200MW$	10	7	112	92	610	623
$\geq 200MW$	0	1	3	3	49	35

Table 13: Distribution of changes in wind generation (definition 2) for different values of ΔT for 2008. Changes of magnitude zero are counted in the positive column in the first row.

Year	15 minute		30 minute		60 minute	
	pos	neg	pos	neg	pos	neg
2007	141	-127	225	-215	361	-325
2008	148	-231	269	-261	390	-346

Table 14: Maximum (positive and negative) changes in wind generation (definition 2) for different values of ΔT for 2007-2008.

Ramp time/sign	2007 Thresholds		2008 Thresholds	
	100	150	100	150
Early am/pos	20	5	11	4
Late am/pos	21	5	17	1
Early pm/pos	26	7	25	6
Late pm/pos	21	2	14	2
Early am/neg	18	4	11	2
Late am/neg	20	4	20	2
Early pm/neg	12	1	14	3
Late pm/neg	22	2	12	3
Total/pos	88	19	67	13
Total/neg	72	11	57	10

Table 15: Time of day occurrences of 30 min ramps at low and high thresholds for 2007 and 2008. The number indicates the number of times a positive or negative ramp event of magnitude greater than the threshold starts in that time period of the day.

Ramp time/sign	2007 Thresholds		2008 Thresholds	
	150	200	150	200
Early am/pos	15	8	9	4
Late am/pos	19	10	12	4
Early pm/pos	29	8	28	8
Late pm/pos	14	3	10	4
Early am/neg	14	4	17	0
Late am/neg	21	4	21	5
Early pm/neg	8	2	10	4
Late pm/neg	16	3	15	4
Total/pos	77	29	59	20
Total/neg	59	13	63	13

Table 16: Time of day occurrences of 60 min ramps at low and high thresholds for 2007 and 2008. The number indicates the number of times a positive or negative ramp event of magnitude greater than the threshold starts in that time period of the day.

			J	F	M	A	M	J	J	A	S	O	N	D
2007	Tr=100	pos	3	15	12	11	0	3	0	0	2	14	10	18
		neg	5	12	11	4	3	2	0	2	3	7	13	10
		tot	8	27	23	15	3	5	0	2	5	21	23	28
	Tr=150	pos	1	2	2	1	0	1	0	0	0	4	2	6
		neg	0	2	2	0	0	0	0	0	0	1	4	2
		tot	1	4	4	1	0	1	0	0	0	5	6	8
2008	Tr=100	pos	11	12	13	5	1	0	3	0	4	1	8	9
		neg	9	7	11	3	4	0	4	2	1	3	7	6
		tot	20	19	24	8	5	0	7	2	5	4	15	15
	Tr=150	pos	1	3	3	1	0	0	0	0	0	0	3	2
		neg	2	1	2	0	1	0	1	0	0	0	2	1
		tot	3	4	5	1	1	0	1	0	0	0	5	3

Table 17: Monthly occurrences of 30min ramps at low and high thresholds for 2007 and 2008. The number indicates the number of times a positive or negative ramp event of magnitude greater than the threshold occurs in that month.

			J	F	M	A	M	J	J	A	S	O	N	D
2007	Tr=150	pos	4	8	8	11	1	2	0	0	4	11	12	16
		neg	5	10	9	3	3	3	1	2	1	7	9	6
		tot	9	18	17	14	4	5	1	2	5	18	21	22
	Tr=200	pos	1	2	2	3	0	1	0	0	1	6	5	8
		neg	2	2	2	0	0	0	0	0	0	1	4	2
		tot	3	4	4	3	0	1	0	0	1	7	9	10
2008	Tr=150	pos	9	10	11	5	2	0	4	0	4	0	8	6
		neg	9	7	11	4	4	2	5	2	1	3	9	6
		tot	18	17	22	9	6	2	9	2	5	3	17	12
	Tr=200	pos	4	2	5	1	1	0	0	0	0	0	5	2
		neg	2	2	1	0	1	0	1	1	0	0	2	3
		tot	6	4	6	1	2	0	1	1	0	0	7	5

Table 18: Monthly occurrences of 60min ramps at low and high thresholds for 2007 and 2008. The number indicates the number of times a positive or negative ramp event of magnitude greater than the threshold occurs in that month.