UA-SVERI Variability Analysis

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Summary and key findings

- Geographic diversity of solar and wind power plants within and among SVERI utilities reduces the aggregate solar and wind variability.
- SVERI aggregate 2027 net load ramps are predicted to be mostly due to the daily solar cycle rather than changes in cloud cover and wind speed.
- Wind and solar ramp statistics have been provided for the observed behavior of VERs in the SVERI member aggregate.
- SVERI solar variability due to changes in cloud cover tends to be greatest when looking at small (under five minute) times scales. Wind variability, in contrast, increases significantly as the averaging time increases.
- A methodology was developed to determine the appropriate amount of extra reserves needed to balance for solar and wind variability.

This report analyzes SVERI utility solar and wind data from June 1, 2014 through November 30, 2014 and 2027 projections. This report does not analyze the impacts of distributed behind-the-meter solar generation.

This report was prepared by the SVERI utilities

and the University Arizona Renewable Energy Network

About SVERI (Southwest Variable Energy Resource Initiative)

Formed in the fall of 2012, SVERI's mission is to evaluate likely penetration, locations and operating characteristics of variable energy resources within the Southwest over the next 20 years. SVERI participants are also exploring tools that may facilitate variable energy resource integration and provide benefits to customers.

SVERI participants include Arizona's G&T Cooperatives, Arizona Public Service, El Paso Electric, Imperial Irrigation District, Public Service Company of New Mexico, Salt River Project, Tucson Electric Power and the Western Area Power Administration's Desert Southwest Region.

About UA REN

The University of Arizona Renewable Energy Network (REN) is a university-wide initiative designed to support the expanded regional, national, and global use of abundant, clean, and economical renewable energy by connecting community and industry to the UA's research and educational programs.

UA REN participants in this report include Will Holmgren (UA Physics, UA Atmospheric Sciences, DOE EERE Postdoctoral Research Fellow), Alex Cronin (UA Physics, Professor), Daniel Cormode (UA Physics, Graduate Student), Antonio Lorenzo (UA Physics, UA Optical Sciences, Graduate Student).

Executive Summary

In 2014, UA REN began working with SVERI members to analyze how Variable Energy Resources (VERs) of wind and solar PV were affecting dispatchable generation requirements. While it is intuitively clear that having variable resources would increase the need for reserves, no analysis on actual subhourly variability had been produced for SVERI participants as a whole.

In this study, UA REN collected and analyzed 10-second data for load, wind generation, and solar photovoltaic (PV) generation. Based on this information, several techniques were used to study variability of load, renewables, and generation. This report presents the effects of solar PV and wind resources on net load ramps in the desert southwest from June through November 2014. Most notably, the analysis produced the following results and conclusions:

- Geographic diversity of solar and wind power plants within and among utilities reduces the aggregate solar and wind variability.
- SVERI aggregate 2027 net load ramps are predicted to be mostly due to the daily solar cycle rather than changes in cloud cover and wind speed.
- Wind and solar ramp statistics have been provided for the observed behavior of VERs in the SVERI member aggregate.
- SVERI solar variability due to changes in cloud cover tends to be greatest when looking at small (under five minute) times scales. Wind variability, in contrast, increases significantly as the averaging time increases.
- An hourly schedule of VERs-backing reserves was constructed using the 95th percentile of 10 minute changes in solar and wind variability.

Near real time SVERI aggregate generation and load data is available at https://sveri.uaren.org/

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Introduction

This report aims to address the following key questions and providing supporting material for these findings:

1. **What is the amount of variability in SVERI utilities?**
   - Solar variability due to changes in cloud cover decreases as averaging time increases, whereas wind variability increases as averaging time increases.
   - The answer depends greatly on the utility, type of generation, time of day, time of year, and time scale. Aggregated ramp statistics are provided for these parameters.

2. **How does geographic diversity affect variability?**
   - Geographic diversity of solar and wind power plants within and among utilities reduces the aggregate solar and wind variability.

3. **How will variability change in the future as more solar and wind is installed?**
   - SVERI aggregate 2027 net load ramps will be greater mainly due to the daily solar cycle rather than changes in cloud cover and wind speed.
   - The answer for each utility depends on how it prioritizes geographic diversity. This report, however, focuses on SVERI-wide net load ramps.

Background of VERs

The remainder of the introduction will provide a basic level of familiarity with variable resources in SVERI. In this report we define Variable Energy Resources as

VERs = Utility Scale Solar PV + Utility Scale Wind

Unless otherwise noted, all references to "solar" will be utility scale solar PV, and all references to "wind" will be utility scale wind. The impacts of rooftop PV generation are beyond the scope of this report.

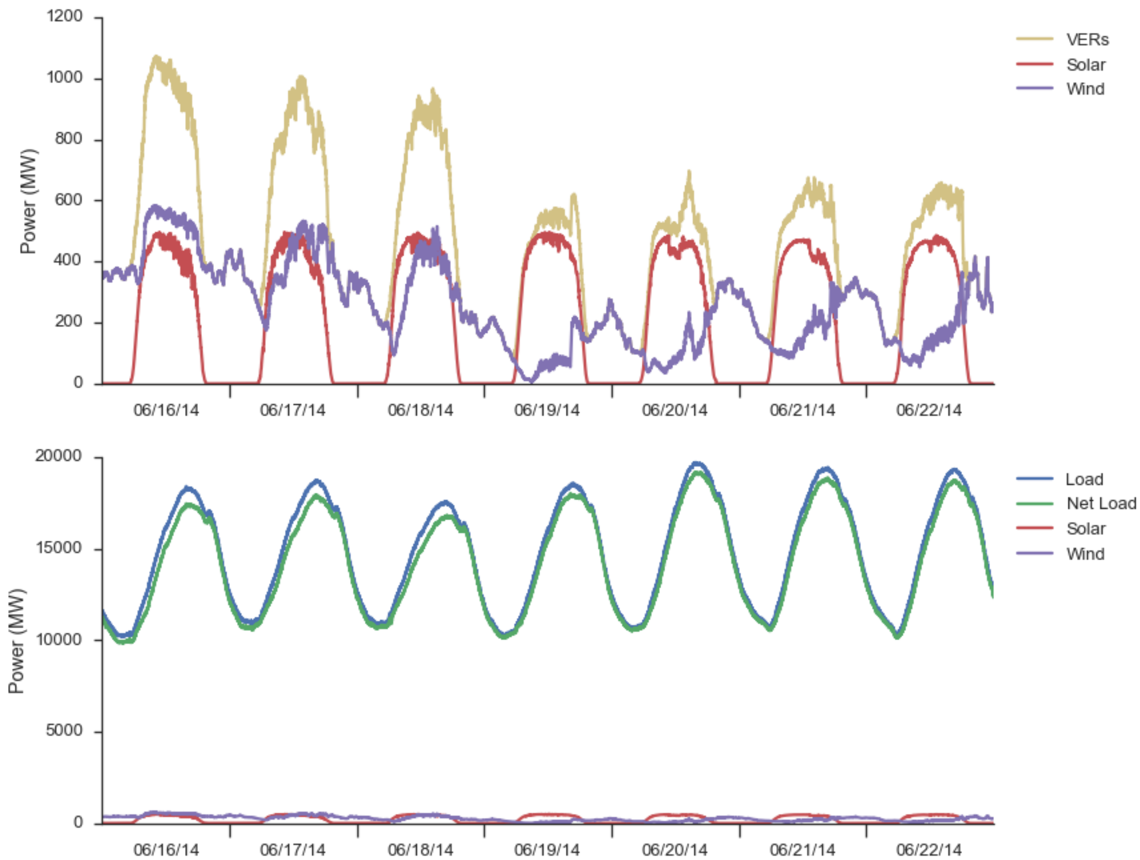


Figure 1. One week of SVERI aggregate solar, wind, VERs, load, and net load data.

Figure 1 shows one week of SVERI aggregate solar, wind, VERs, load and net load. This week shows a particularly large amount of renewable power, at some times almost 500 MW from solar and slightly more than 500 MW from wind, for a total on June 16, 2014 exceeting 1 GW for several hours. Wind and solar generation reduced the peak load by 500 to 1000 MW each day of this week. This can be seen in the Net Load line, which has a smaller peak.

To highlight one day, one can look at the 95th percentile of VER production on June 19 as well as the percent of load that is covered by that production. The total VERs production is 657 MW, which is a 4.6% penetration of load.

Near real time SVERI aggregate generation and load data is available at https://sveri.uaren.org/

Summary of SVERI Members' VERs and Load

The following table summarizes load, solar, and wind production data from June 1, 2014 through October 31, 2014. All numbers are in MW.

	Load	Net load	VERs	Solar	Wind
average	14,297	13,991	306	170	136
std	3,133	3,043	206	190	105
min	8,271	8,167	0	0	0
25%	11,749	11,535	128	0	55
50%	13,790	13,479	268	33	110
75%	16,995	16,618	463	381	191
max	22,319	21,869	1,074	497	601

Table 1. SVERI Aggregate Load and VER statistics

Current amount of VERs variability

Variability can be quantified in a large number of ways. We will use one of the simplest metrics: maximum change in average power. Figure 2 shows the maximum changes in November 2014 midday SVERI aggregate solar and wind output at several averaging time windows. By focusing on midday (11:00-14:00) ramps we can focus on the ramps due to cloud cover and wind speed variability while minimizing the expected ramps due to solar position.

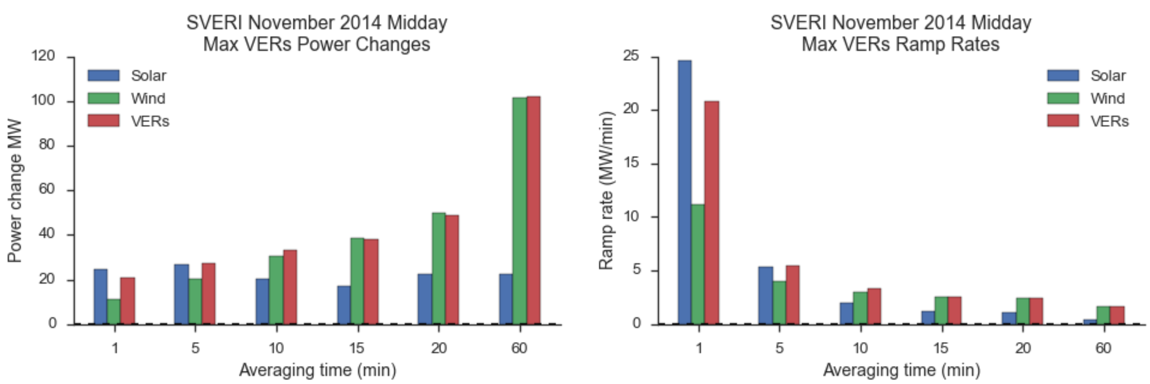


Figure 2. November 2014 midday SVERI aggregate changes in power and ramp rates.

As seen on the left side of Figure 2, changes in average solar power are similar across the 1 minute to 60 minute time windows. In contrast, average wind output increases with longer time scales.

We can also express these changes in power in terms of MW per minute ramp rates. In this particular case, the ramp rates decrease as the time window increases, meaning that the actual rate of change is lower during longer time scales. The ramp rates decrease because the changes in power increase more slowly than time window increases.

Table 2. Maximum 10 minute and hourly change in solar and wind power between 12:00 and 13:00 for each month (2014).

Month	Solar 10 Minute Change	Solar One Hour Change	Wind 10 Minute Change	Wind One Hour Change
June	19	17	64	76
July	24	37	71	59
August	32	46	57	50
September	31	41	76	53
October	23	27	64	60
November	20	22	67	61

While this table only shows the maximum change between 12:00 and 13:00 to remove the effects of solar positioning, wind can result in much greater ramps during other times of day, up to 80 MW in 10 minutes and 140 MW in one hour.

Geographic Diversity and Variability

The SVERI data show that geographic diversity reduces the variability of solar and wind generation as a fraction of capacity. We therefore recommend that all SVERI utilities maximize geographic diversity in the deployment of future solar and wind power plants. Figure 3 shows a map view of the SVERI solar and wind power plants, and a second map with the power plants scaled by their nameplate capacity ratings.

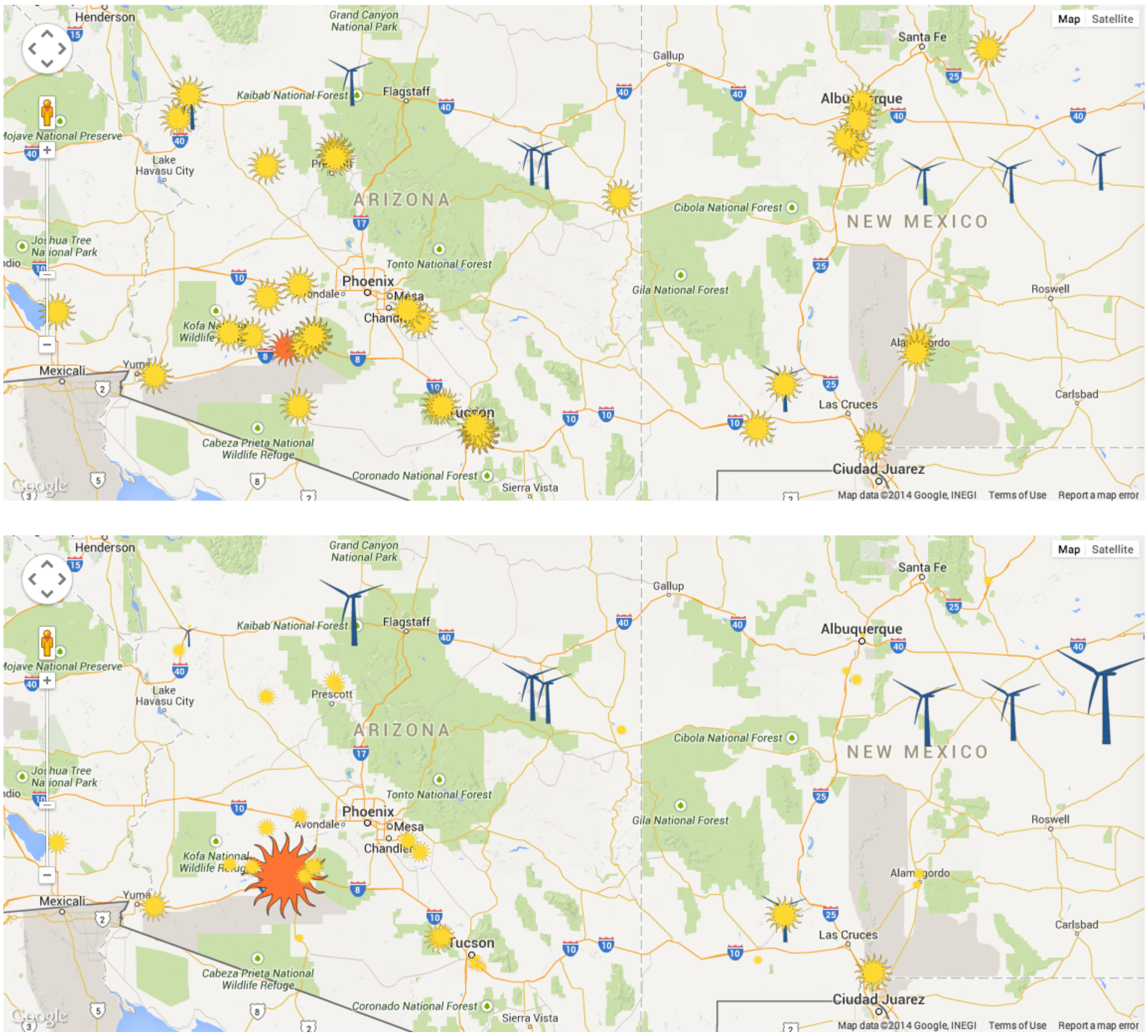


Figure 3. SVERI solar and wind power plants unscaled and scaled by system size. The large orange sun is the Solana CSP power plant, which not included in the present study. An interactive version of this map is available at https://sveri.uaren.org/

To compare the variability across utilities and the SVERI aggregate, we have used a *variability factor* defined as

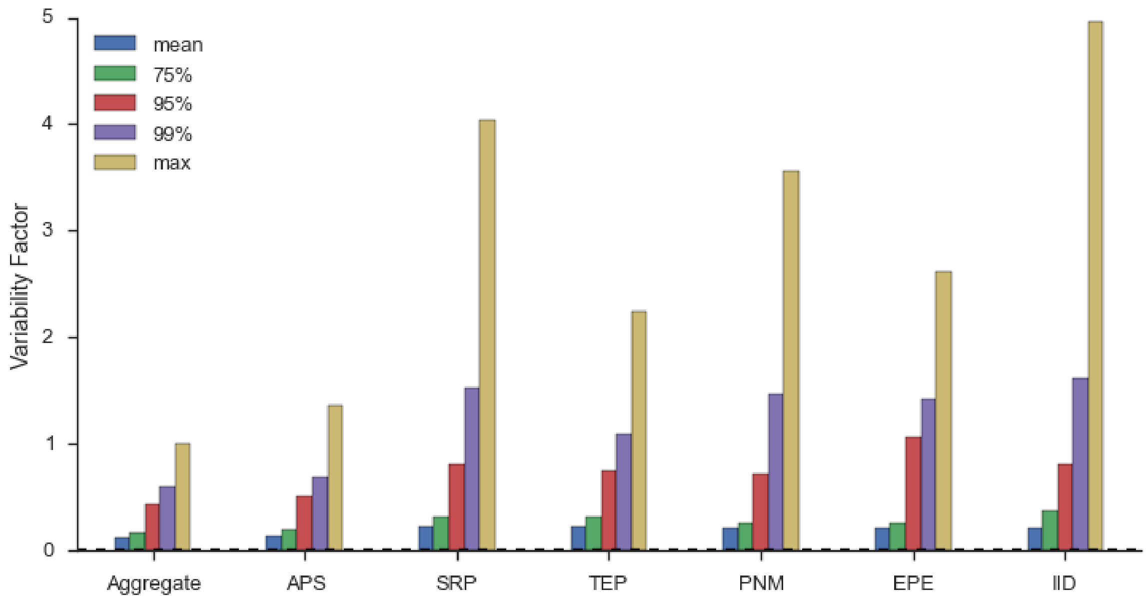
Variability Factor = Utility variability metric / SVERI aggregate variability metric

We chose to calculate variability factors for changes in 15-minute average VERs generation:

Variability Factor = {max,mean,etc.} utility 15-minute change / max SVERI aggregate 15-minute change

Figure 4 shows the results of these calculations. Variability factors less than 1 mean that the variability is less than the maximum 15-minute SVERI variability, and variability factors greater than 1 mean that the variability is larger than the maximum 15-minute SVERI variability.

Utilities with more geographically diverse VERs tend to have smaller variability factors. To investigate if this relationship remains true for smaller and more likely ramps, we calculated the variability factors for the 75th, 95th, and 99th percentile ramps and the mean ramp. The geographic diversity trends are similar for these smaller ramps.



	Aggregate	APS	SRP	TEP	PNM	EPE	IID
max	1	1.4	4	2.2	3.6	2.6	5
99%	0.6	0.7	1.5	1.1	1.5	1.4	1.6
95%	0.4	0.5	0.8	0.8	0.7	1.1	0.8
75%	0.2	0.2	0.3	0.3	0.3	0.3	0.4
mean	0.1	0.1	0.2	0.2	0.2	0.2	0.2

Figure 4. 15 minute variability factors for the mean, 75th, 95th, 99th percentiles, and maximum for each SVERI utility. Utilities with more geographically diverse VERs tend to have smaller variability factors regardless of the likelihood of the ramps.

Variability Projections

SVERI renewable generation is expected to increase on average by a factor of 4 by 2027 based on estimates developed on past projects, trends and other subjective factors. The projections discussed here are unofficial and are for the sole purpose of analyzing the impact renewables could have in the area. For readability, the analysis in this section will focus on VER estimates used for year 2027 compared to current loads.

Figure 5 shows our projection of the net load in 2027 for each month of the study period. The load curves are creating by averaging the load at each minute of the day across each month. We also performed this averaging for solar and wind production to obtain the average VERs generation and net load. Next, we multiplied the solar and wind production data by their growth factors to calculate the 2027 VERs generation and net load. Projected load growth and the impact of DG solar is beyond the scope of this report.

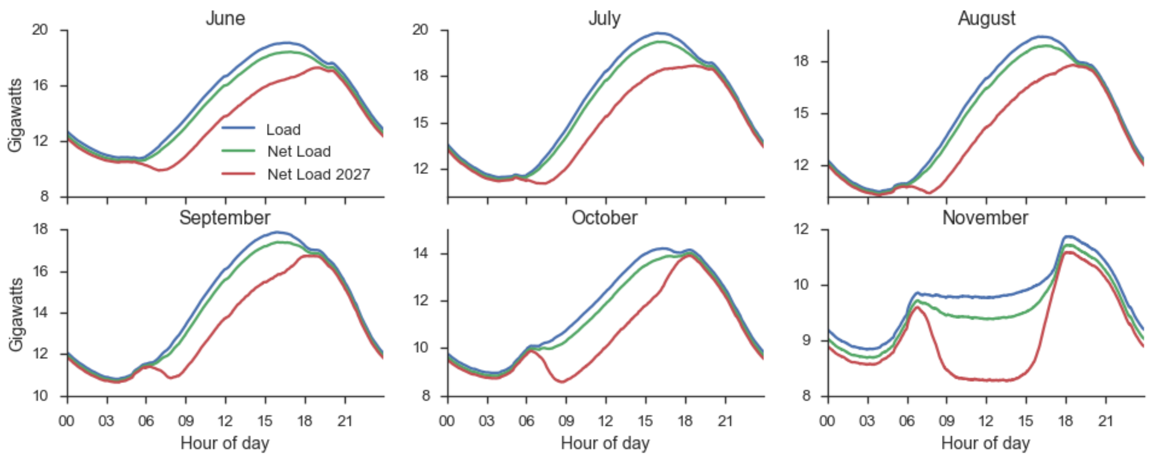


Figure 5. SVERI 2014 load, 2014 net load, and 2027 projected net load. The 2027 net load projection assumes that the 2027 load is identical to 2014 load. Projected load growth and the impact of DG solar is beyond the scope of this report.

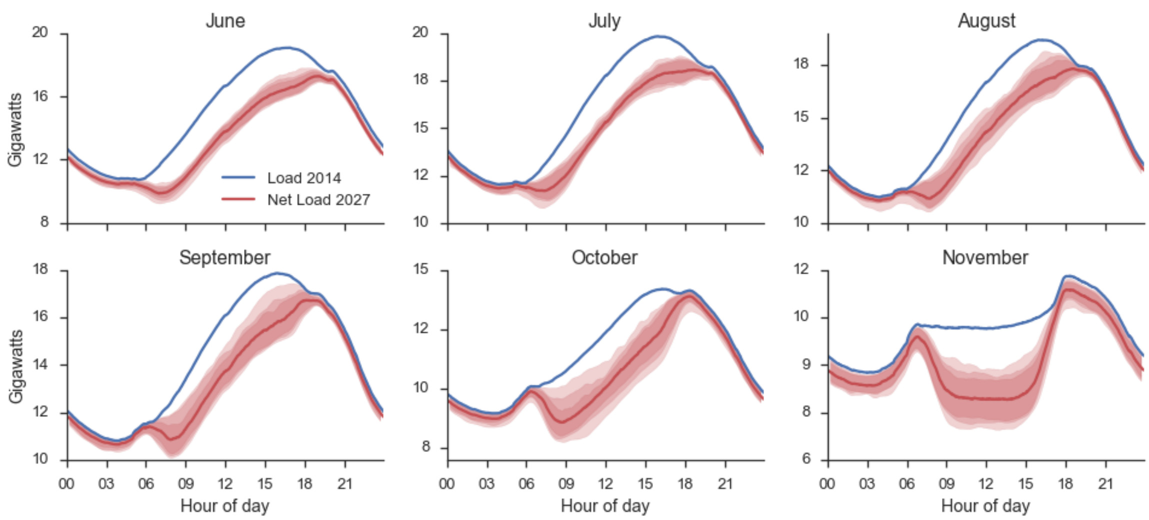


Figure 6. SVERI average 2014 load (blue lines), projected average 2027 net load (red line), and projected 2027 net load range (red area). The shading shows the range from the minimum and maximum, 5th and 95th percentile, and 10th and 90th percentile of VERs generation and thus net load variation.

Figure 6 shows the same 2014 average load and 2027 average net load, but also includes a shaded area to indicate the possible range of VERs generation and net load. Compared to the daily load cycle, the net load range is smaller in June and July than in August-November.

A potentially difficult scenario is a rapid change from the minimum to the maximum VER generation when the net load is small. We observed SVERI aggregate hourly VERs changes of as much as 100 MW for wind and 25 MW for solar in November 2014, as shown in Figure 1. These ramps were not coincidental. Assuming no net change in SVERI aggregate geographic diversity, and assuming unlikely coicidental ramps, we can expect this maximum ramp rate to grow to a maximum possible value of 325 MW/1hr in 2027.

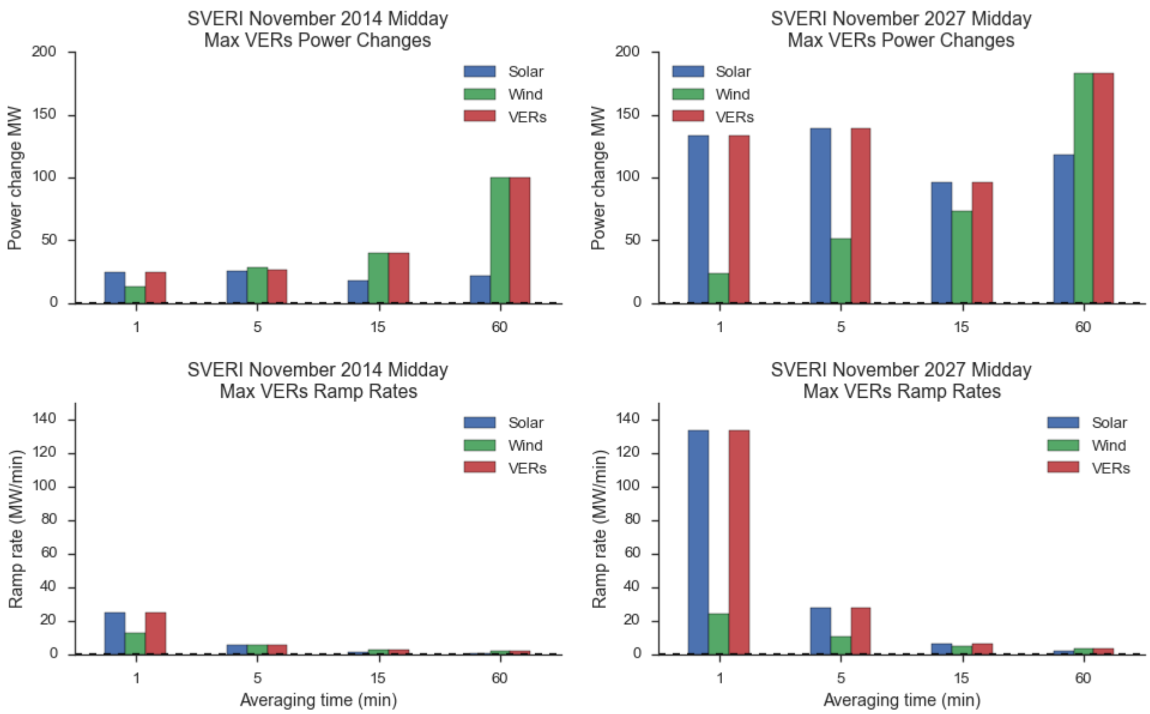


Figure 7. Comparison of SVERI November 2014 and 2027 changes in power and ramp rates for solar, wind and VERs at different averaging times. See Figure 2 for a simpler version of this figure.

Figure 7 shows that, if there were no more geographic diversity in plant locations, ramp rates are forecasted to be about four times greater by 2027 because of the planned increase in variable energy resources. This will have implications on utility operations and suggests the need for tools such as flexible generation, transmission resources, energy storage, and demand response. The right mix of tools for SVERI utilities is an open question.

Regulation Reserve Schedules

Knowledge of the typical VERs ramp rates may be used to construct a regulation reserve schedule to guard against unexpected changes in VERs generation. The proposed reserves schedules are calculated solely based on observed ramp rates and only include limited knowledge about how utilities operate.

The VERs-backing reserve schedules are only intended to cover the unexpected changes in VERs generation. We build upon previously discussed results to calculate the absolute value of changes in VERs generation. There are a number of possible ways to construct VERs-backing reserve schedules: for example, three different time frames (1 minute, 10 minute, 1 hour) and three different levels of coverage (90%, 95%, 100%). Based on conversations with SVERI members, we chose to make reserves schedules using the 95th percentile of 10 minute changes in VERs generation. These reserve schedules are shown in Table 3.

Next, we summarize the procedure used to create these schedules. For each utility,

1. Average the 10 second VERs production data down to 10 minute data.
2. Calculate the difference between each 10 minute average data point.
3. Calculate the absolute value of the differenced data. Call this the ramps.
4. For each month, collect the ramps into bins labeled by hour of the day. For example, the ramps that occur at 6/1/2014 10:00 and 6/20/2014 10:30 both go into the 6/2014 hour-10 bin. There approximately (60/10)*30=180 ramps per bin.
    a. Within each bin, sort the ramps from smallest to largest.
    b. Calculate the 95th percentile of the sorted ramps for each bin. This is the data shown in Table 3.

Table 3 shows that additional reserves between 10 MW and 60 MW may be recommended for the SVERI aggregate, depending on the time of day and month of year. Such reserves would cover 95% of the changes in 10 minute average VERs generation in 2014.

Table 3. Regulation reserves schedules to cover 95% of changes in 10 minute average VERs production in 2014. All numbers are in MW.

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Aggregate																								
Jun-14	31	27	24	22	22	29	35	46	32	22	24	20	25	28	35	37	42	53	54	39	29	35	37	28
Jul-14	25	29	22	20	26	21	38	42	37	27	19	22	22	26	36	37	34	48	54	40	29	26	27	26
Aug-14	17	15	18	17	14	13	39	44	29	25	19	23	25	39	45	48	42	58	53	24	21	23	23	13
Sep-14	16	15	17	14	18	16	36	44	41	28	21	21	21	34	25	33	43	61	39	21	21	23	21	20
Oct-14	20	19	21	17	23	12	26	50	40	40	34	21	19	21	24	33	52	50	24	23	16	15	25	21
Nov-14	19	23	16	25	18	17	14	44	46	30	27	22	19	19	21	49	46	38	27	23	29	20	32	20

Conclusion

In this study, UA REN collected and analyzed 10-second data for load, wind generation, and solar photovoltaic (PV) generation. Based on this information, several techniques were used to study variability of load, renewables, and generation. This report presented the effects of solar PV and wind resources on net load ramps in the desert southwest from June through November 2014. Most notably, the analysis produced the following results and conclusions:

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