The value of spatial diversity in reducing variability in wind power production across the eastern plains of Colorado; A constrained optimization approach

The following analysis shows a reduction in variability of wind power production in Colorado due to spatial diversity. The implication is that wind plants may be able to garner an increased capacity value as a system as opposed to an individual site if this method is followed. In addition greater penetrations of variable generation may be able to be integrated in to the electrical grid at reduced cost if the variability inherent in the system can be minimized.

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Introduction

Wind energy production is now widely accepted as a viable energy resource but not a significant capacity resource. Thus the current GW of wind energy generation budding up over Colorado is seen to the electric utility industry as providing energy and thus fuel savings but not reliable power. This is a function of wind energy only being available when the wind is blowing fast enough to generate, but not to fast typically between 4 meter per second and 25 meters per second. Given the utility companies responsibility to provide energy when it is needed as opposed to solely when the wind is blowing one can understand the lack of capacity value given to wind energy resources.

The value of spatial diversity as it relates to the capacity of wind is a common argument for decreased variability in wind energy production and thus an increase in potential capacity value to the wind industry. For example, if three wind farms are constructed in different locations it is likely that if the wind is not blowing at one location it may be blowing at another location. Thus, multiple locations can provide more capacity value via the benefits of spatial diversity.

The analysis that follows took wind metrological data from ten locations around the eastern plains of Colorado and modeled the energy generation over the course of a year (1997). With the modeled wind generation outputs the data was then optimized to reduce the variability of the system by picking the locations for development that had the greatest amount of complimentary energy generation. Detailed method can be found in the following series of papers, {}.

Results

A reduction in variability can be achieved via an optimization of wind development sites across the eastern plains of Colorado. Ten wind development sites were analyzed and optimized with the intent to reduce variability in power production. The sites analyzed are displayed below in Figure 1.

Site 1	Calhan
Site 2	Cheyenne Wells
Site 3	Genoa
Site 4	Gobblers Knob East
Site 5	Gobblers Knob West
Site 6	Livermore
Site 7	Mesa de Maya
Site 8	Pawnee Buttes
Site 9	Peetz
Site 10	Wauneta

Figure 1: The ten wind sites analyzed for optimization in Colorado

This analysis shows that there is a significant advantage to geographically distributing wind resources. One of the primary advantages is the drastic reduction in time in which there is zero power production from the optimized system where as each individual location spends a significant amount of time at zero power production.

Table 1: Each of the 10 Colorado wind sites analyzed as well as the Colorado optimized system power production reliability shown as percent of the year in 5% bins of power production.

% of Capacity	Calhan	Cheyenne Wells	Genoa	Gobblers Knob E	Gobblers Knob W	Livermore	Mesa de Maya	Pawnee Buttes	Peetz	Wauneta	Optimized system
0%	16.88%	9.81%	12.15%	14.00%	13.37%	22.11%	14.57%	10.15%	13.30%	9.57%	0.06%
5%	26.26%	31.13%	21.70%	20.70%	17.09%	31.19%	23.32%	21.22%	16.58%	23.17%	17.58%
10%	14.49%	12.11%	15.53%	13.28%	14.94%	11.39%	15.57%	14.46%	15.05%	12.93%	18.38%
15%	9.87%	8.66%	10.57%	9.49%	12.27%	5.43%	11.15%	9.78%	10.68%	9.50%	13.42%
20%	7.27%	6.96%	6.79%	7.00%	8.68%	4.26%	8.94%	5.39%	7.51%	7.16%	11.38%
25%	4.68%	4.70%	5.51%	6.58%	7.25%	2.85%	6.10%	4.67%	5.96%	6.82%	8.84%
30%	3.07%	4.24%	4.11%	4.87%	5.92%	2.40%	4.62%	3.62%	4.25%	5.58%	7.10%
35%	2.47%	3.90%	3.84%	4.13%	3.69%	2.41%	3.11%	3.20%	3.06%	3.90%	5.80%
40%	1.92%	2.96%	2.89%	3.31%	3.42%	1.68%	2.37%	2.45%	2.15%	3.40%	4.67%
45%	1.50%	2.24%	2.01%	2.32%	2.57%	1.92%	1.53%	1.76%	2.37%	2.88%	3.61%
50%	1.55%	2.04%	1.93%	2.07%	1.67%	1.21%	1.37%	1.82%	1.67%	2.32%	2.52%
55%	1.14%	1.52%	1.68%	2.36%	1.83%	1.22%	1.18%	1.64%	1.76%	2.07%	1.82%
60%	0.80%	1.21%	1.03%	1.42%	1.28%	0.70%	0.84%	0.92%	1.46%	1.24%	1.16%
65%	0.80%	1.38%	0.96%	1.46%	0.94%	1.18%	0.67%	1.22%	1.62%	1.05%	0.91%
70%	0.61%	1.03%	0.99%	1.00%	0.64%	0.70%	0.70%	1.79%	1.04%	0.99%	0.75%
75%	0.49%	0.80%	0.75%	0.78%	0.56%	0.92%	0.38%	0.99%	0.99%	0.80%	0.54%
80%	0.51%	0.51%	0.80%	0.59%	0.51%	0.78%	0.37%	0.73%	0.86%	0.68%	0.53%
85%	0.49%	0.21%	0.59%	0.59%	0.32%	0.65%	0.48%	1.08%	0.83%	0.49%	0.50%
90%	0.39%	0.47%	0.54%	0.49%	0.39%	0.25%	0.46%	1.16%	0.68%	0.55%	0.29%
95%	0.23%	0.39%	0.51%	0.56%	0.26%	0.67%	0.22%	0.61%	0.97%	0.34%	0.09%
100%	4.59%	3.73%	5.13%	3.01%	2.41%	6.08%	2.07%	11.32%	7.21%	4.55%	0.06%

Table 1 illustrates the above conclusion that each of the above individual locations spends a significant amount of the 1997 annual cycle at zero production. Conversely the Optimized system spends 0.06% (5 hours and 15 of the year) of the 1997 annual cycle at zero power production.

Furthermore, the optimized system spends less time per year at peak power production then any of the individual systems. When managing for variability in the electric energy system both the challenge of too much energy and not enough energy is a challenge.

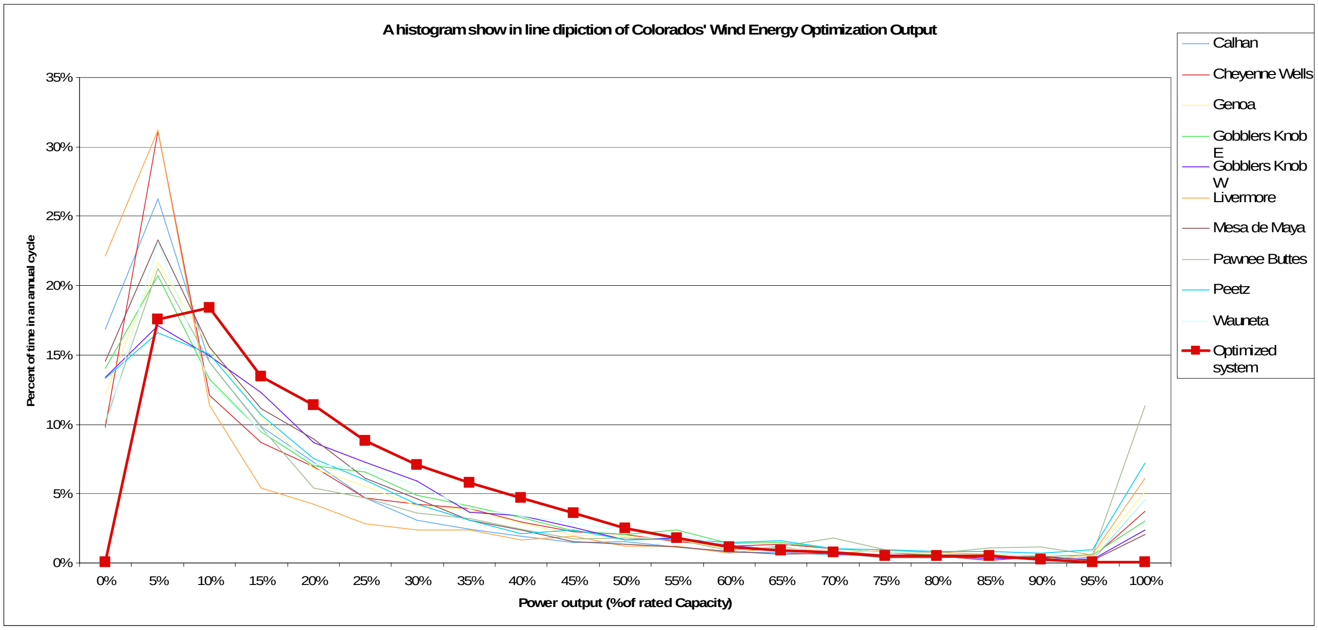

Figure 2: A lined histogram depicting reliability of wind power production against an annual cycle

Figure 2 is a graphical depiction of Table 1showing each of the individual wind power production sites modeled spending significant portions of the annual cycle at zero power production. Conversely the optimized system spends near zero percent of the year at zero production. Additionally the optimized system avoids the spike in power production typical of the individual development sites.

Conclusions

The implication of this work is that choosing locations for wind development in part based on benefits to system reliability and reduction in variability is possible. There are benefits to spatial diversity. These results suggest that one may want to plan wind development based on variability reduction optimization. Should variability reduction be achieved the electric utility may see both decreased cost of integration as well as an increase in the total amount of variable power production dispatchable onto an electric grid.

Next Steps

- Integrate wind data from western Colorado
- Integrate additional sources of renewable generation
- Integrate demand response and load dispatch
- Integrate energy storage