758: Applications of the Renewable Energy Network Optimization Tool (ReNOT) for use by Wind & Solar Developers: Part II.

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ABSTRACT

As the renewable energy industry continues to grow so does the requirement for atmospheric modeling and analysis tools to maximize both wind and solar power. Renewable energy generation is variable however; presenting challenges for electrical grid operation and requires a variety of measures to adequately firm power. These measures include the production of non-renewable generation during times when renewables are not available. One strategy for minimizing the variability of renewable energy production is geographical diversity. Assuming that a network of renewable energy systems feed a common electrical grid, site diversity ensures that when one system on the network has a reduction in generation others on the same grid make up the difference.
Part one of this paper introduced ReNOT and its capabilities. This paper presents two case studies on applying ReNOT to the wind and solar farm industry, respectively.

Keywords: Renewable Energy, wind power, solar power, site optimization

1. INTRODUCTION

Northrop Grumman Corp. and Rocky Mountain Supercomputing Centers (RMSC) have leveraged the power of supercomputing, advanced meso-scale atmospheric and high resolution regional climate modeling, and high-fidelity meteorological data to offer a new service called MORE (Maximizing & Optimizing Renewable Energy) POWER, aka The Renewable Energy Network Optimization Tool (ReNOT). This commercial technology reduces the financial risk in renewable energy project development by selecting the best combination of locations for either wind and/or solar farm placements that will result in the highest generation and lowest aggregate intermittency of power.

ReNOT accomplishes this by integrating historical wind or solar data with topographic and land cover information to evaluate 12 km^2 grids (4 km^2 for clouds) within a defined geographic area, such as a state or county, to determine which site placements will generate the most power with the least variance in production. Rather than relying solely on predictive wind models, ReNOT uses a sophisticated optimization algorithm along with high performance computing to evaluate billions of combinations of sites that meet the performance criteria set forth. The algorithm takes advantage of our assumption that geographical diversity will lower intermittency maximizing usable power and minimizing firming requirements.
ReNOT has also included a high resolution regional climate change simulation to calculate how evolving climatic conditions will impact the energy production potential of each site's asset lifecycle (up to 50 years). The result is a multi-site wind or solar energy project eligible for favorable financing terms due to its superior power variance score. Once built, the project can save millions in operating costs related to firming contracts thanks to the low intermittency in power generation.

As part of collaboration with RMSC and the State of Montana a study was performed to estimate the optimal locations of a network of wind farms. In addition a study to exercise a proof of concept for a solar application was also performed for South Florida. This paper highlights the results from each study. For background on the data bases utilized for this study as well as the algorithm used for optimization the reader is referred to part I of this study ([1]Alliss et. al., 2010).

2. WIND APPLICATION

The objective of this study was to determine whether a four site of wind farms with a name plate capacity of 374 MW could be found that was superior to an existing four site network with idential name plate capacity. ReNOT was setup to allow only locations in the state of Montana. Comparisons were made to four existing wind farm locations including Glacier with a 210 MW name plate capacity, Horseshoe Bend with a total capacity of 9 MW, Diamond Willow with a capacity of 20MW and Judith Gap with a total capacity of 135 MW (figure 1).

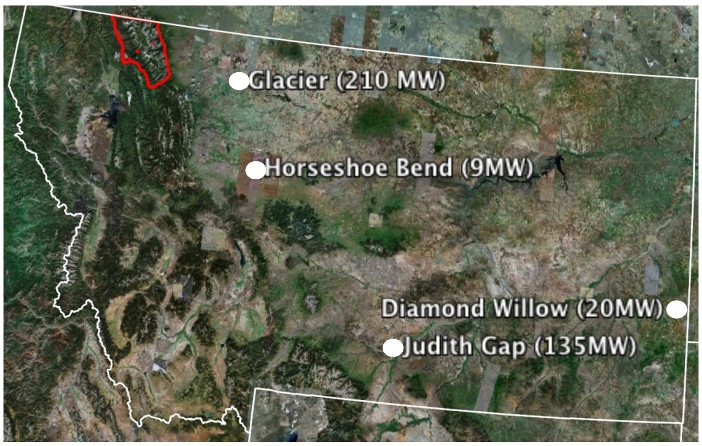

Figure 1: locations of four wind farms in Montana with a total name plate capacity of 374MW.

We developed three different metrics in which to pick sites. Metric 1 (M1) picks sites that converges on the single best location for power production, on average. Metric 2 (M2) picks sites that maximizes geographical diversity, even at the expense of very poor aggregate power. Metric 3 (M3) picks sites based on the previous day's mean power, and accounts for short-term variability (i.e., 1 hour). In a sense M3 attempts to approximate usable power by minimizing ramping events which are so important to industry. In addition we investigated several performance metrics including Mean Power, Usable Power, and ramping event frequency. A ramping event is defined as an increase or decrease in power production over the course of one hour. Of interest was the frequency of ramping events that exceeded 10% of total capacity for the network. Networks with few ramping events are markedly superior to networks producing otherwise identical aggregate power.

The optimization was run over the 15 year period (1995-2009) of hub-height wind data (40 meters AGL). Figure 2 indicates the existing wind farms in white while the optimized network is shown in yellow. The ReNOT derived network produces 58% more usable power than the four existing and operating wind farms denoted in white. In addition, the optimized four site network produces three times fewer significant ramping events. Note that the configuration of the optimized network contains two sites that are relatively close together but just down wind of Glacier National Park (shown in red outlined area). The other two sites have much more geographical diversity. This indicates the optimization was able to find a trade off between peak power and more consistent day to day power.

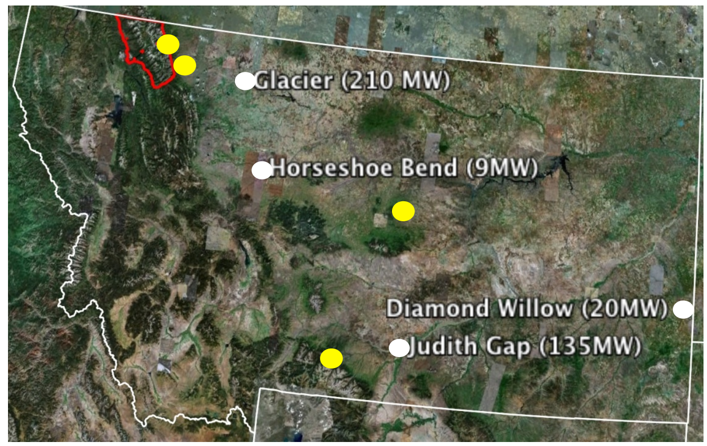

Figure 2: Results from the ReNOT optimizing showing the optimal M3 network (yellow dots).

Table 1 below shows statistics from the ReNOT optimization. The raw power from the four existing sites are shown as well as the *usable power* (ie., M3 metric) approximation. In addition, the frequency that the networks exceeded 10% of the total name plate capacity are shown. The first two rows shows the values of the existing four sites but with a) their original nameplate capacity configuration and b) assuming each site has the same name plate capacity. The remaining four rows show the optimized network but with different combinations of the name plate capacity. The first configuration, named closest network, is that network whose individual name plate capacity was closest in distance to the existing sites. The 2nd configuration was that network which produced the highest raw power, the 3rd configuration assumed each site in the optimized network had equal name plate capacity of 93.5MW. As Table 1 indicates the usable power is on the order of 20% - 25% lower than the raw power but it is believed that the usable power approximation is that power which is much more reliable and dependable to the market. In addition, despite the different nameplate capacity configurations, the optimized network produces about 58% more usable power than the existing four site network. Ramping events at the 10% level were also much less common for the optimized networks compared with the existing networks. A calculation of the network capacity factor (NCF) was computed for the existing and optimized network. The NCF is analogous to the site capacity factor used by the industry today but in this case it represents the ratio of the total usable power for the network to its name plate capacity. In this case the NCF was 0.17 and 0.27 for the existing and optimized networks, respectively.

Site Configuration	Raw Power (MW)	Usable Power (MW)	Ramping 10% (%)
Judith Gap, Horseshoe Bend, Glacier, D.Willow (use name plate values)	85	63	2.5
Judith Gap, Horseshoe Bend, Glacier, D.Willow (use equal power 93.5MW)	81	63	2.1
ReNOT (Closest network)	124	101	1.0
ReNOT (Highest Power)	125	99	1.7
ReNOT (Highest Stability)	121	98	1.9
ReNOT (using equal power, 93.5MW)	122	100	1.3

Table 1: Wind study results performed over the State of Montana.

3. SOLAR APPLICATION

A solar study was performed to find the optimal set of four solar farms on the Central and Southern Peninsula of Florida. The optimization was performed over a 15 year period (1995-2009) using a GOES derived cloud analysis at 4km and 15 minute resolution, respectively (Alliss et.al., 2011). As with the wind study we developed a cost function that emphasizes network stability, total power and day ahead forecastability. Networks with more consistent day to day cloud cover and are more accurately forecastable by a day in advance will be favored by ReNOT. Figure 3 shows the results of the optimization. Results were compared to an existing set of four sites (two of which are proposed currently (25MW @)). The existing sites are located at Cape Canaveral (10MW) and Desoto (25MW), Florida. These sites are represented by x's on the map. The three top optimized networks are shown by yellow, red, and white dots. These three networks had the highest S3 (analogous to M3) score as indicated in the legend. ReNOT places the optimal networks along the West Coast for Florida and producing approximately 10% more usable power than the existing / proposed sites. This result is mainly due to the minimum in cloud cover along the west coast of Florida as shown in Figure 4. The ReNOT simulation would have picked sites over the water but this was prohibited by the land-sea-lake mask used in the code. The influence of correlations is partially minimized by the restricted optimization area (yellow bounding box in Figure 3) and the strong minimum in clouds observed along the west coast. All three networks produced a useable power of approximately 85MW compared to the 145MW name plate capacity. This produces a NCF of approximately 59%. The existing/proposed sites produce a NCF slightly less than 54%. Ramping events (as measured at the 10% ramping level) are nearly equal to those of the existing/proposed sites (Table 2) at approximately 34% of the time.

Site Configuration	Raw Power (MW)	Usable Power (MW)	Ramping 10%
Desoto, Space Coast, two proposed sites (145 MW)	86.8	77.6	34.0
ReNOT Network (145MW)	92.1	85.6	33.1

Table 2: Results from the solar ReNOT study over Central Florida for the period 1995-2009.

The runs performed in this study were made with out regard to other practicle restrictions for example, building in state parks, population centers or within proximity to electrical grid infrastructure. However, we are currently adding this capability into ReNOT.

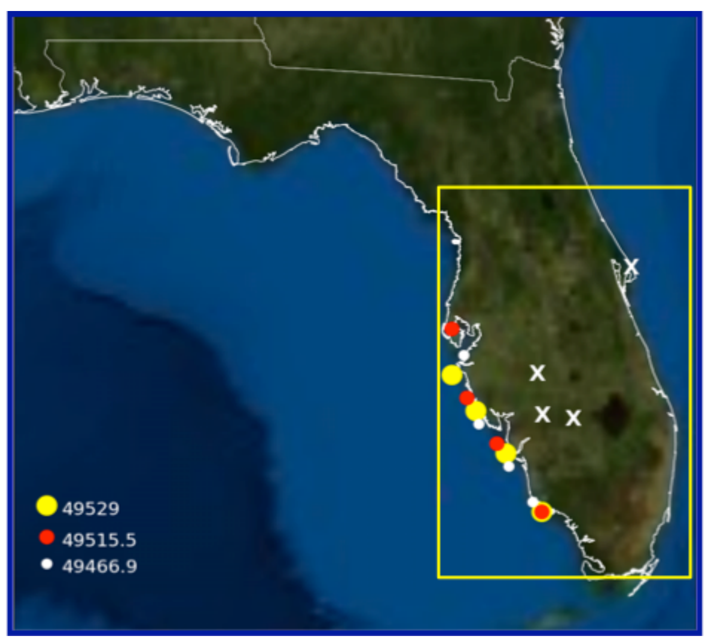

Figure 3: ReNOT results for a solar power optimization study over Central and Southern Florida

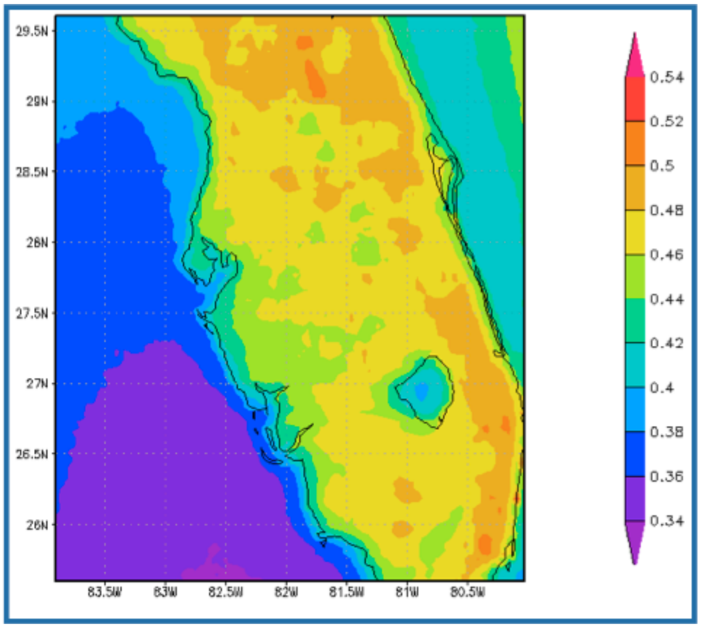

Figure 4: Mean cloud fraction over the peninsula of Florida (1995-2009). Note the minimum of clouds located along the west coast of the state.

We were also interested in investigating what the P90 statistics might look like for the networks, particularly as a function of time of day. Table 3a,b shows the probability of exceeding different useable power values for the (a) optimized network and the (b) existing/proposed network. These statistics are based on the entire 15 year period. Results show the optimized network provides a higher P90 value particularly at noon then the unoptimized network.

Probability of Power Output Exceeding a Given Value				
	50%	75%	90%	99%
7am-8am	91.95	66.38	33.95	8.63
8am-9am	127.25	100.53	54.40	16.87
9am-10am	138.75	108.05	67.25	25.10
10am-11am	144.05	112.48	74.90	34.77
11am-12pm	156.20	125.00	89.30	47.10
12pm-1pm	158.00	125.93	87.80	53.20
1pm-2pm	152.60	114.93	77.10	50.97
2pm-3pm	139.50	100.20	56.15	42.47
3pm-4pm	117.55	71.40	37.50	31.77
4pm-5pm	91.10	48.05	22.70	20.57
5pm-6pm	56.40	26.13	11.60	10.70
6pm-7pm	21.50	8.43	4.30	3.67

Table 3a. Probability of power output exceeding a given value for the optimized network as a function of time of day.

Probability of Power Output Exceeding a Given Value				
	50%	75%	90%	99%
7am-8am	106.65	80.00	39.60	9.73
8am-9am	138.95	110.43	60.25	18.27
9am-10am	143.05	113.65	66.65	26.30
10am-11am	144.40	113.13	66.15	36.53
11am-12pm	153.65	118.15	69.50	48.73
12pm-1pm	154.60	113.30	69.30	54.10
1pm-2pm	143.60	101.23	59.05	51.50
2pm-3pm	126.45	71.70	47.30	42.50
3pm-4pm	101.60	52.13	34.80	31.70
4pm-5pm	67.85	33.93	21.00	20.33
5pm-6pm	41.15	17.80	11.20	10.60
6pm-7pm	15.20	6.73	4.10	3.60

Table 3b. Same as (a) but for the unoptimized network.

To investigate the impact of satellite resolution might have on the results, we constructed a 1km cloud climatology based on daytime GOES visible imagery for the year 2009. We then evaluated the usable power from the optimized networks using the original 4km dataset for 2009 only as well as the 1km dataset. The results are shown in Table 3 below.

Site Configuration	4km Usable Power (MW)	1km Usable Power (MW)
Desoto, Space Coast, two FP&L proposed sites (145 MW)	72.8	79.4
ReNOT Network (145MW)	86.9	92.6

Table 4: Results of a comparison between using 4km and 1km clouds on useable power for 2009 only.

In general we found that the 1km dataset was clearer in 2009 compared with the 4km dataset by approximately 5-8%. This is not surprising since at 1km resolution we are able to see the holes that exist between the convective clouds which are dominant in this part of the state. The holes are not as resolvable at 4km resolution. The impact on useable power for both networks is increase by 7-8%. This indicates that it may be more advantageous to develop a full fifteen year climatology of clouds to get a better representation of the useable power.

4. SUMMARY

The Renewable Energy Network Optimization Tool (ReNOT) has been developed to assist in the optimal placement of networks of wind and/or solar farms. ReNOT optimizes site selection to maximize usable power, by minimizing power intermittency and maximizing base load power of the system. It takes into consideration constraints on placement such as: location of transmission lines, population density, land costs and others. Use of this tool can assist in minimizing the conventional energy reserve requirements of the utility industry. In addition, ReNOT is a powerful tool that can assist policy makers, regulators, regional public stakeholders, transmission operators, and individual renewable operators and investors. This disruptive technology is reducing the financing and operating costs of wind and solar energy projects and accelerating the return on investment.

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REFERENCES

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