Wind Power & Energy Market Modeling

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Introduction

Wind power generation is notoriously difficult to predict due to the erratic nature of wind velocities. It is also constrained by the availability and location of optimal sites, usually forcing farms to be build relatively far away from the load source. As a result, wind farms are risky and expensive to integrate into existing energy grids.

This project attempts to model the behavior of a power system with an integrated wind farm using MatPower to execute power flow equations that show the relationship between power supply and demand

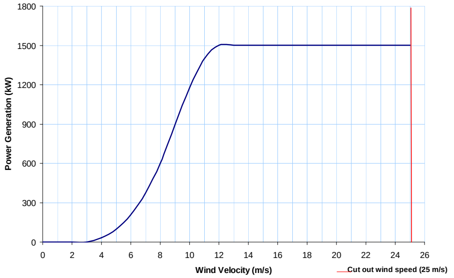
Project Goals

- Add wind farm to standard 5 bus power grid model
- Establish base cases with which to test the system
- Use power flow equation to determine how the grid model behaves with different load level and wind speed pairings

Methods

- Representative generator was added to a standard five bus power model (fig. 1) reflecting the power production capabilities of the average wind farm size (83 units) for the General Electric 1.5 MW wind turbine
- Hourly load levels were collected from Pennsylvania Electric Co. (fig. 2) and scaled according the six-bus model maximum load capacity
- Wind speeds for Bradford County, PN during the month of January were used to determine appropriate wind speeds for the base cases.
- Nine base cases (table 1) pairing three load levels and three wind power outputs was established based on an 83 turbine wind farm
- A power curve for the GE 1.5 MW turbine was developed to plot the relationship between wind velocity and power generation (fig. 3).
- MATPower program used to run power flow equation to determine:
- The output of each generator (**S**)
- The voltage at each bus (**V** = V∠θ)
- The power flow on each line (Pflow)

Figure 3. GE 1.5 MW turbine power curve



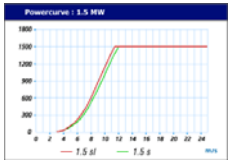


Figure - GE 1.5 MW Turbine

Figure 1. Six bus power grid model with added wind farm

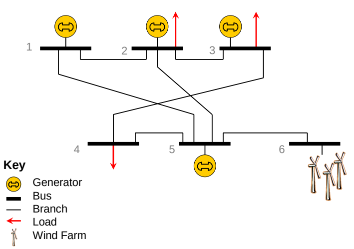


Table 1. Trial pairings of wind power and load in six-bus test model

	Load (MW)		
Wind Speed:Power (m/s):(MW)	Max (1500)	Moderate (1350)	Low (1200)
Max (12:125)	Trial 1	Trial 4	Trial 7
Moderate (8:51)	Trial 2	Trial 5	Trial 8
Low (4:3)	Trial 3	Trial 6	Trial 9

Figure 2. Average daily load levels by hour January 2008

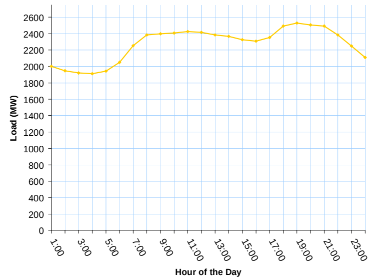
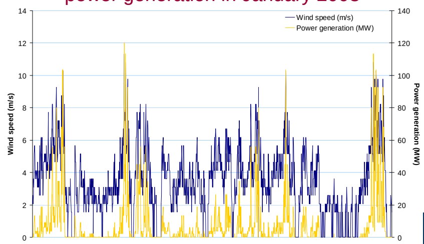


Figure 4. Hourly wind speeds and wind farm power generation in January 2008

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System Summary
How many?                 How much?              P (MW)           Q (MVAr)
---------------------     -------------------  -------------  -----------------
Buses                  6     Total Gen Capacity    1654.0       -1500.0 to 1500.0
Generators             5     On-line Capacity      1654.0       -1500.0 to 1500.0
Committed Gens         5     Generation (actual)   1533.3             40.7
Loads                  3     Load                  1500.0              0.0
  Fixed                3       Fixed               1500.0              0.0
  Dispatchable         0       Dispatchable          -0.0 of -0.0     -0.0
Shunts                 0     Shunt (inj)           -0.0                0.0
Branches               7     Losses (I^2 * Z)       33.32            182.03
Transformers           0     Branch Charging (inj)   -               141.4
Inter-ties             0     Total Inter-tie Flow    0.0               0.0
Areas                  1
                            Minimum                      Maximum
                       -------------------------  --------------------------------
Voltage Magnitude   0.959 p.u. @ bus 2          1.001 p.u. @ bus 3
Voltage Angle     -15.83 deg   @ bus 4          0.00 deg   @ bus 1
P Losses (I^2*R)             -                  16.14 MW    @ line 1-2
Q Losses (I^2*X)             -                  96.85 MVAr  @ line 1-2
================================================================================
Bus Data
Bus       Voltage          Generation             Load
  #   Mag(pu) Ang(deg)   P (MW)   Q (MVAr)   P (MW)   Q (MVAr)
----- ------- --------  --------  --------  --------  --------
    1  1.000    0.000    552.32     10.37       -         -
    2  0.959  -14.132    200.00      0.00    800.00      0.00
    3  1.001   -9.054    520.00      0.00    400.00      0.00
    4  0.984  -15.830       -         -      300.00      0.00
    5  1.000   -8.214    210.00     45.42       -         -
    6  1.000   -6.967     51.00    -15.11       -         -
                        --------  --------  --------  --------
               Total:   1533.32     40.67   1500.00      0.00
================================================================================
Branch Data                                                                |
Brnch   From   To    From Bus Injection   To Bus Injection     Loss (I^2 * Z)
  #     Bus    Bus    P (MW)   Q (MVAr)   P (MW)   Q (MVAr)   P (MW)   Q (MVAr)
-----  -----  -----  --------  --------  --------  --------  --------  --------
   1      1      2    398.63     41.12   -382.49     38.45    16.142     96.85
   2      1      5    153.69    -30.75   -148.86     36.48     4.827     21.72
   3      2      3    -52.12    -25.66     53.34     -3.75     1.217      5.17
   4      2      5   -165.39    -12.79    171.34      7.59     5.948     17.85
   5      3      4    117.40      1.79   -116.01     -8.56     1.391     13.91
   6      4      5   -183.99      8.56    187.52      1.35     3.524     24.67
   7      6      3     51.00    -15.11    -50.73      1.96     0.266      1.86
                                                             --------  --------
                                                   Total:     33.316    182.03
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Results

- Voltage angle rose above the voltage angle used to determine the maximum system load & power output in *trial 2* and *trial 3*.
- Model only "fails" during peak loads, when wind speeds are not at their recorded maximum.

Implications

- When wind speeds fall below their maximum recorded speed, which will be most of the time, the system will be able to accommodate this power slump by allocating more load onto the other generators. This occurs even when the wind farm is generating as much as it can under the give wind conditions.
- It is too risky to replace all or most of the generators in this model with wind farms because the variability of wind does not match up with load demands (figs. 3 & 4). Moreover, it is incredibly expensive ($2 mil per turbine) to build a wind farm large enough to replace one of the larger generators. Therefore, wind energy may be best paired with more reliable, higher producing energy source when integrated into commercial energy systems.

Next Steps

- *Immediate:* Generate a more realistic model of probabilistic wind generation by performing a Monty Carlo statistical analysis to select wind farm output to use in MatPower.
- Create a probability distribution of errors between forecasted and actual wind speed in real time. Pair this with probabilities of thermal generator or transmission line failure in real time.
- Model the effects of moving the wind farm closer and farther away from the load center. Find cost data and energy policies to estimate the cost of adding a wind farm and all of the required infrastructure
- Ultimately want to determine the relationship between wind farm location, system fortitude and monetary trade-offs.
- *Further along:* Select a definite study location (probably NY) and model the system constrains by using a larger bus model to mirror the real generating capacity and load levels.

Acknowledgements

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