Homework 3 Submission – CBE 9413 Intro to Sustainable Energy Systems

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Disclaimer: Copilot was used to develop pseudo-code.

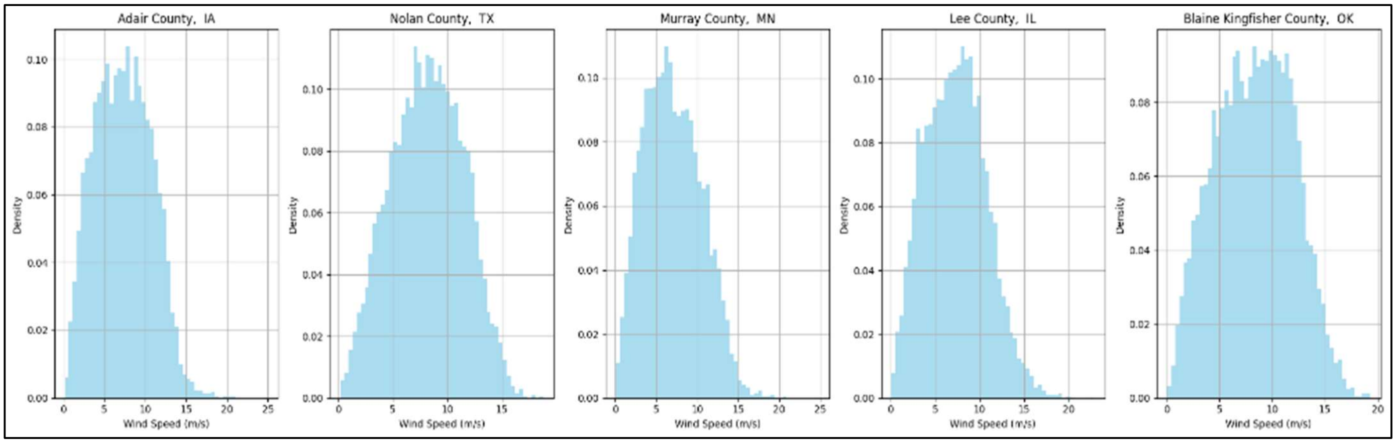
Problem 1

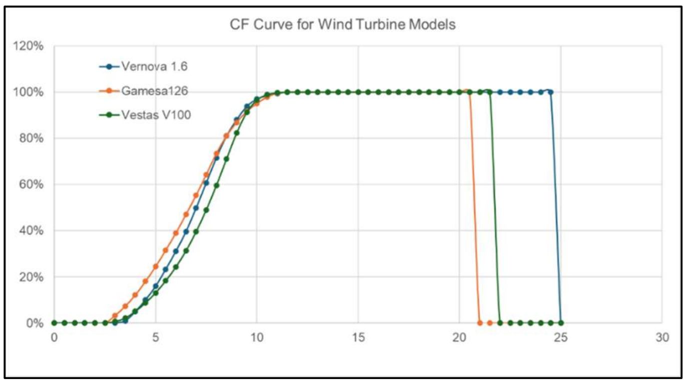
1. **Methodology**
   1.1. We need to estimate hourly wind power CUF profile at **5 different locations using three different turbine models.**
   1.2. We will parameterize the given GitHub code through location parameters (lat, lon) and turbine model parameters (including power curve file for each turbine model).
   1.3. This ensures that the model can call each set of params at once using For loop and generate csv file containing hourly wind power CUF for each turbine model at each location.
2. **Findings and key takeaways**
   2.1. The results of the simulation of wind turbine models at each location are as follows:

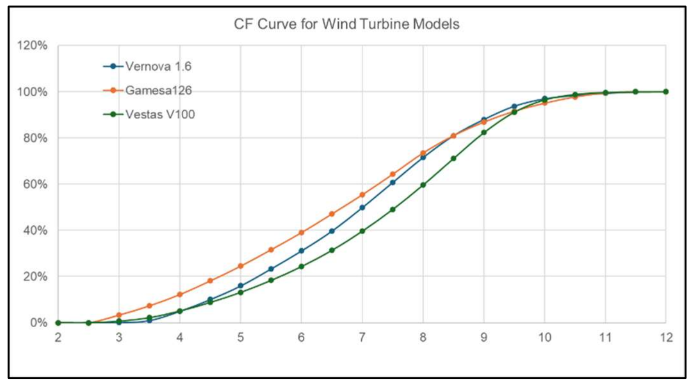
SN	Turbine Model	Gamesa G126	GE Vernova 1.6	Vestas V100
1	Adair County, IA	45.4%	43.2%	40.3%
2	Blaine/Kingfisher County, OK	52.4%	50.7%	48.1%
3	Lee County, IL	45.1%	43.0%	39.9%
4	Murray County, MN	42.2%	39.9%	37.0%
5	Nolan County, TX	52.5%	50.6%	47.5%

   2.2. **Gamesa G-126** model turns out to be the **best** in terms of **annual average CF** for each location.
   2.3. On a system level, **distribution of wind speeds will dictate the choice of turbine model** :
      2.3.1. For wind speeds between 2 – 9 m/s, CF of Gamesa is the highest of the three models but at the expense of higher installed capacity (2.5 MW per turbine vs 1.6 MW or 1.8 MW).
      2.3.2. For wind speeds > 11 m/s, CF of all three turbines is ~100%, meaning that the turbine with the lowest rated capacity (Vestas 1.6 MW) will be ideal to minimize installed capacity.
   2.4. Based on the wind speed distribution of each location, either Vestas or Gamesa turbine should be preferred to be installed. (This choice is also reflected in the optimization results of Q2).
      2.4.1. Right skewed wind speed distribution – Gamesa
      2.4.2. Near normal wind speed distribution – Vestas

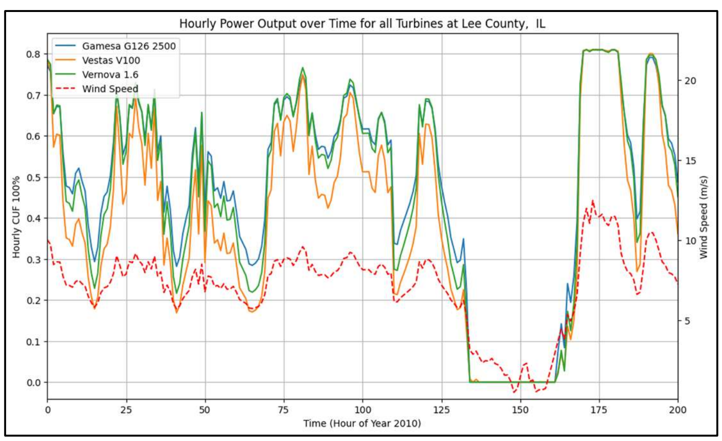
Figures: Top: Wind speed distribution across locations; Bottom Left: CF curve for turbine models (entire wind speeds); Bottom Right: CF curve for turbine models (low wind speeds)







2.5. From a snapshot of hourly CF and wind speed for each turbine model at Lee County, IL, we can see that **wind CF is very sensitive to wind speed** (nature of wind CF curve).



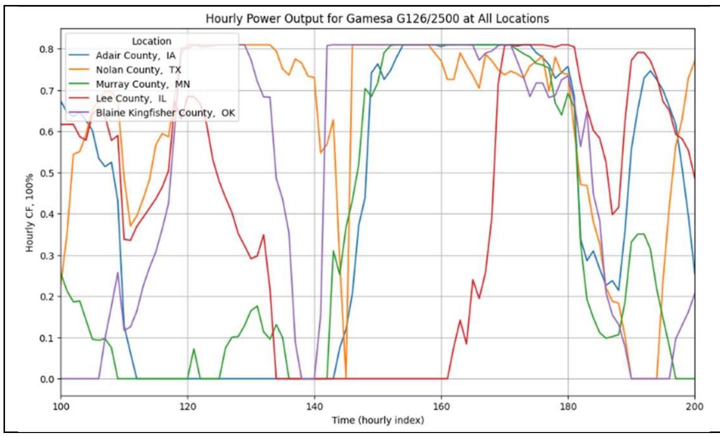
2.6. For wind speeds less than the **cut-in speed** (130 – 150 hrs of 2010), turbine CF drops to zero.

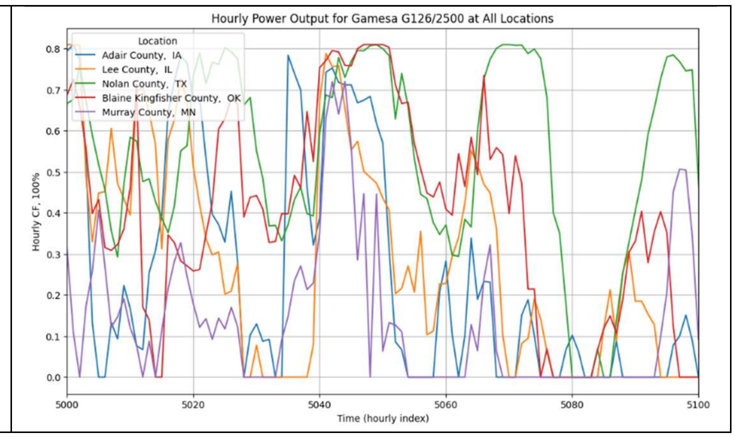
2.7. For wind speeds higher than 5 m/s, turbine CF increases sharply to 81% (100% - 19% losses).

2.8. The effect of hysteresis cover could not be seen in this dataset because wind speeds > 15 m/s are hard to observe at these locations.

Part B

1. We will plot snippets of hourly wind power CF for Gamesa G126 at all locations.
2. **Hourly variability:** We observe that there is **high variation in the hourly wind CF over a day** at all locations compared to solar PV CF.
3. Unlike solar PV which follows a bell-shaped CF curve on sunny days, wind CF in an hour of day is much more intermittent and random.
4. **Day-to-day variability**: Wind power is also much more intermittent over same hours of different days across locations.
5. Thus, there is **huge scope for geographical smoothing** in case of wind power.





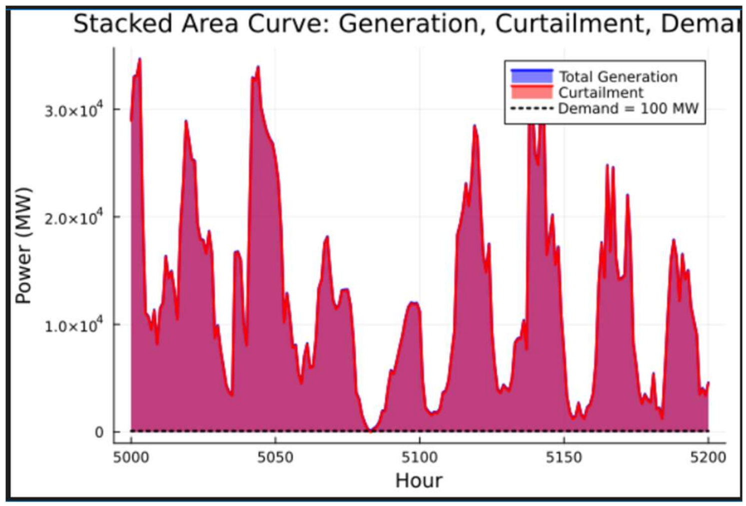
<u>Problem 2</u> <u>(Math corresponding to the optimization problem is described in the suppl. Julia code)</u>

<u>Part A</u>

a) <u>Locations 1 – 5</u>

SN	Location	No. of turbines			Total Cap., MW
		Gamesa 2.5 MW	Vestas 1.8 MW	Vernova 1.6 MW	
1	Nolan County, TX	-	7568	-	~13,622
2	Blaine County, OK	487	-	-	~1218
3	Adair County, IA	-	8868	-	~15,962
4	Murray County, MN	527	-	-	~1318
5	Lee County, IL	-	7470	-	~13,446

1. Total installed capacity: **45,566 MW**
2. Curtailment: **99.5%** of annual production
3. Figure on the RHS shows a snapshot of hourly wind power production, demand and curtailment.



b) <u>Locations 1,2,4 5</u>

1. There is **no feasible solution** to this problem because the hourly demand constraint (100 MW) cannot be fulfilled at certain hours of the year.
2. Upon closer inspection, we can see that there are **two hours when only Location 3** (which is not included in the optimization) **is producing wind power.**

c) <u>Location 3 only</u>

1. There is **no feasible solution** to this problem either because the hourly demand constraint (100 MW) cannot be fulfilled by a single wind power location.
2. We can see that there are ~1000 hours when Location 3 is not producing any wind power.

Findings and key takeaways

1. In the present case, system is overbuilt to ensure 100 MW hourly demand at certain low wind CUF hours, leading to surplus production in other hours getting curtailed.

2. Variable Renewable Energy (VRE) sources such as solar PV and wind power cannot fulfill baseload power demand on standalone basis.
3. We need some level of flexibility in the system (demand/ supply side) to bring down the overcapacity of VRE and reduce curtailment.
   3.1. Demand-side flexibility:
      3.1.1. Instead of **100%** demand fulfilment (DF) **every hour**, we can relax demand fulfilment to 80%-90% of baseload over higher time horizon (say, **90%** demand fulfilment of 100 MW base load demand **every month**).
      3.1.2. Alternatively, we can **penalize the wind system for non-fulfilment of hourly demand** and minimize total installed costs.
   3.2. Supply-side Flexibility:
      3.2.1. Include **ESS/ grid power in the supply mix** to dispatch at low/ no wind power hours.
      3.2.2. This has dual advantages: part of excess supply can be stored in the ESS and dispatched later, bringing curtailment down and reducing overbuilding capacity.

Part B – Inter Annual Variability in Wind Power for Locations 1 – 5

We will use the earlier Julia code and change wind CF related constraints by appropriately loading the hourly wind CF files for each location.

a) Year 2010

The optimized results are already reported in Part A.

b) Year 2011

Infeasible solution. There is one hour (6087) at which wind power CF at all locations is zero leading to non-fulfilment of hourly demand constraint.

c) Year 2012

Infeasible solution. There is one hour (6087) at which wind power CF at all locations is zero leading to non-fulfilment of hourly demand constraint.

Key takeaways

1. Wind power modelling is more complicated than solar PV energy due to **variable nature of wind resource availability across different weather years**.
2. A system optimized with 2010 weather data may not deliver as expected in 2011 or 2012.
3. A guidebook from US DoE suggests obtaining data for several years or a representative year (such as Typical Meteorological Year) which is highly correlated across years for reliable estimation. https://windexchange.energy.gov/small-wind-guidebook#enough