Due: Nov 27, 2024

Energy: Science, Technology, and Society

Project 2

Prospects for a 200-MW Wind Farm in Northwestern New York

The main goal of the project is to evaluate and illustrate the utility of wind power generation in the NW New York area. Motivation for the project is provided by stated U.S. state and federal energy policies to replace dispatchable conventional power generation based mainly on coal, gas, and nuclear plants by renewable energy technologies.
Research the tasks defined below, collect and analyze relevant data, and write a detailed technical report on the results of your study (MSWord or similar).
Show and discuss samples of original data in tables and graphs. Show and explain examples of pertinent calculations. Justify, based on your own study, your specific conclusions and recommendations for energy policy makers.
In the project definition below, explixit costs have been suggested for some components, as provided by publications of the wind research community and/or the wind industry.

Project Tasks:

1. **Wind Technology Background Brief:** Explain briefly the functions and operating principles of the main components of a wind tower (foundation/base, tower, nacelle, rotor/hub, gearbox, generator, control). For example, explain how the generator power output can be controlled by pitch of the rotor blades and within what power range. How fast do the blades rotate (rpm=rotations per minute), what are typical tip speeds in mph?

2. **Data Collection and Analysis:** Assess the data base for surface wind patterns in upstate New York, Ontario Lake on-shore, for the installation of a major wind farm.
   a) Retrieve the NOAA mean daily surface windspeed (υ) data at the airport ROC in Rochester (NY) for the **year 2023** as representative for the larger area.
   b) Generate an XLS data table for the probability distribution $P(\upsilon)=\Delta N(\upsilon)/N\Delta\upsilon$ from the observed data. Sort the *N* data points and appropriately chosen speed intervals ($\Delta\upsilon$).
   c) Correct the distribution for the systematic increase of windspeed from ground level to a 95-m turbine hub height.
   >>>>> Consult Explanations to Task 2 below.

3. **Calculate Single-Turbine Output:** Assume the popular wind turbine model Vestas V100-1.8 MW for the large wind farm to be designed. Given the daily wind data obtained in 2) and the design power curve $Output_e(\upsilon)$ specified below for the turbine, deduce the daily mean (and capacity factor) of the fluctuating electrical power generated by a single turbine.
   a) What are two areas in New York State most suitable for on-shore windfarms and why?
   b) Digitize the 60-Hz power curve given in the provided graph.

c) Produce sample graphs of the daily power generated by one turbine during a winter and a summer period during 2023, with each period 2-weeks long.
d) Present and discuss tabulated power data month by month.
e) Deduce the mean generated power, averaged over the entire year 2023.
f) Identify days in 2023 when the turbine rotor blades would have to be feathered because of high winds/storms?
g) Which months had periods with wind speeds insufficient to generate power larger than 10% of rated (nominal)?

4. **Single Wind Tower Construction Cost & Connection:** Use $1.1/W as the mean of the current total cost for turbine, rotor, and nacelle enclosures. Additing current (2023) mean values for *balance of system* (BOS) and *soft costs* brings the total installed single-tower cost to $1.75/W nominal power. The tower proper is typically constructed of tubular steel, concrete, or a hybrid combination. See papers by Singh and Huang provided on the course website.
   a) Calculate how many (N_t) wind towers are needed for a windfarm to generate a mean electrical power of 200MW in 2023, given the wind speed distribution observed.
   b) What is the required total installed wind capacity and required capital to realize a windfarm of this performance?

5. **Site Layout:** Based on the results obtained in Tasks 3 & 4, design a wind farm with N_t wind towers in NW New York. The farm should be an array of N_t individual towers with 200 MW of **average delivered total power** at the wind conditions prevailing during the surveyed time period. Farm design criteria are 1. Favorable wind patterns and soil consistency at site location, 2. efficiency of turbine electricity generation, 3. minimum land footprint, 4. minimum length of cable connections and maintenance access pathways to all turbines.
   a) Design and sketch schematically a simple geometrical pattern (☐) in a Cartesian grid for the onshore site of the windfarm. Assume wake-safe distances between turbines (10 x D_{rotor}, Betz Law).
   >>>>Consider the following land requirements:
   b) Allow an area of ¼ acre (☐) for the foundation of the base of each wind tower.
   c) Add gravel ($17/cyard) paved access/service pathways (25′ width, 2′ deep foundation) to and between turbines.
   d) Allow one 5′-wide strip of land along the maintenance pathways for underground power cables connecting each turbine to its transformer/inverter substation.

6. **Converter Substations & Connections:** Each substation (construction cost $3M) can service 20 turbine generators. The substation collects, transforms, and delivers the power long-distance via one high-voltage DC (12kV-69kV) cable. Use (a low) $0.50/foot for the power cables needed to connect the tower generators to the converter substation. >>>> Preferred location of a station is at the periphery of the wind farm.

7. **Capital Investment and O&M Cost:** Estimate the installation capital required for the wind towers and the environmental (land) footprint of the farm with access pathways. According to the *U.S. Department of Agriculture*'s Land Values 2020 Summary, an acre of land

in NY costs $3,100 on average. As an alternative to purchase, lease of farm land is available at local interest (annuity) rates of $125/acre per year for a 25-year lease. The wind farm costs for operation and maintenance (typically 1 technician per 10 towers) amount to approximately $30/kW per year.

8. **Bare and Levelized Cost Estimate:** Assume similar operational conditions (as in 2023) to prevail over the 25-year lifetime of the farm and a fixed capital annuity rate (capital interest, 6.5%).
   a) Estimate the direct cost ($/kWh) of electrical power delivered by the windfarm.
   b) Estimate the corresponding levelized cost ($/kWh) of electricity.

9. **Emissions:** Calculate the amount of concrete and steel used for the construction of the wind towers of the farm. Use tables given below for estimates and interpolations of the materials.
   a) Estimate the CO_2 amount generated in the construction of the wind towers from these two sources.
   b) Estimate the CO_2 amount avoided by the wind generated electrical energy over the lifetime of the farm.
   Emissions: 1.85 t of CO_2 per ton of steel, 80.9 kg of CO2 per t of structural concrete.

10. **Report:** Present a summary of the main results from your study in the publication-ready form of a technical report/research paper, like suggested by the provided template. Organize data in tables, illustrate them by figures/graphs of good (readable) quality, describe trends. Define data reduction procedures and present examples of relevant calculations and derivations.

>>>>>> Additional tasks for Chem 468

11. Wind Speed Distribution:
   a) Fit the measured wind speed data in terms of the Weibull distribution (consult https://wind-data.ch/tools/weibull.php?lng=en or https://real-statistics.com/distribution-fitting/fitting-weibull-regression/) and determine the characteristic Weibull parameters.
   b) Produce graphs of relevant raw and fit data.

12. **Upgrade to Dispatchable Power:** To guarantee an available (dispatchable) total power level of P_{total} =200 MW, the wind farm power output has occasionally to be supplemented by standby power. Evaluate the cost differential electrical power for the options,
   a) The required power differential is provided by a local nat-gas-powered plant (0.2-GW_e nominal, base load). To garantee 0.2 GW_e spot demand, the backup plant must be running continuously at a minimum of 15% nominal power. Use local retail cost (6¢/kWh) for calculating the cost of backup electricity.
   b) In a hybrid 10MW installation, intermittend wind power is supplemented by a co-located 1MW power Li-Ion battery bank, covering (fully charged) up to a 4-hr lull. The cost of electricity retrieved from such a 4-hour, 1MW battery is of the order of $3/MWh. Calculate the power cost of this combination (wind farm plus on-site battery backup).

Project 2, Task 2 (Explanations/Hints):

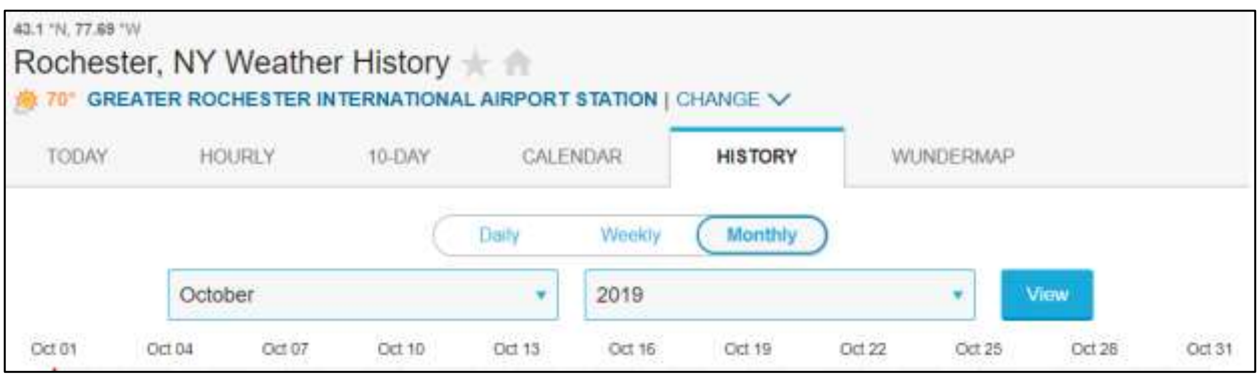
In preparation for the execution of Project 2, locate the web site below (or another official site) that posts hourly, daily, etc. numerical data for observations of wind speeds at the Rochester International Airport (ROC). Download numerical wind data from the site and insert them into a spreadsheet. Below are some screenshots from using the site.

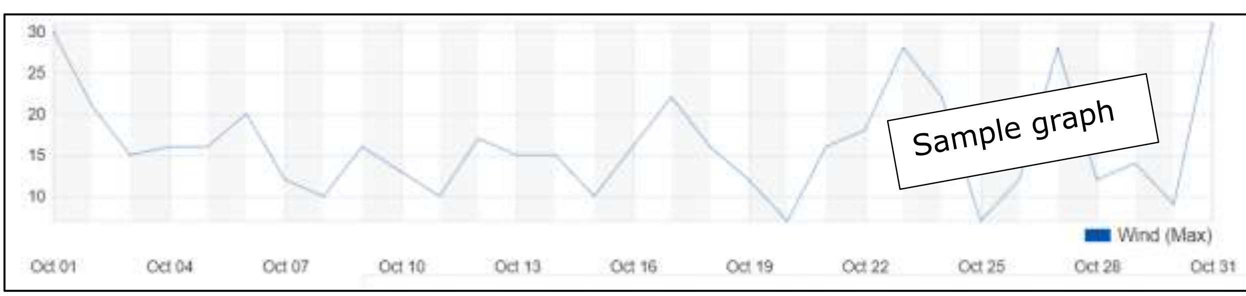
https://www.wunderground.com/history/monthly/us/ny/rochester/KROC/date/2019-10

Daily Observations

Time	Temperature (° F)			Dew Point (° F)			Humidity (%)			Wind Speed (mph)		
Oct	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max		
1	88	75.1	68	71	66.3	63	93	76.0	48	[illegible]	[illegible]	6
2	70	60.8	53	68	57.4	45	100	88.8	72	21	11.2	0
3	57	53.6	50	56	50.3	43	100	88.6	71	15	8.6	0
4	57	49.9	45	54	43.6	38	97	79.9	61	16	8.7	0
5	59	50.2	40	43	38.1	35	90	65.8	44	16	7.9	0
6	75	63.6	55	60	52.2	41	80	66.9	53	20	9.9	5
7	64	58.4	53	59	53.9	49	97	85.7	65	12	5.2	0

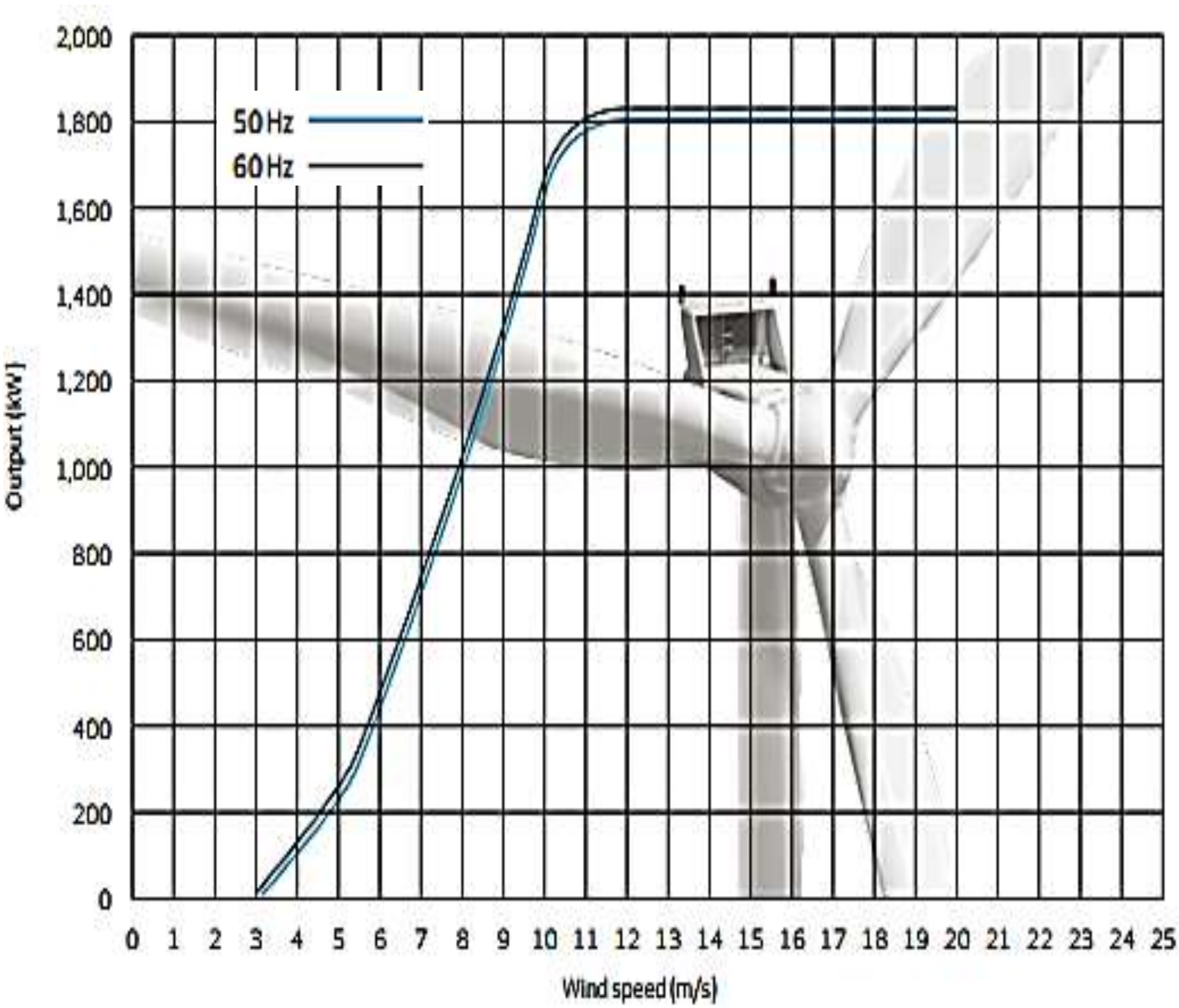
Sample data





Project 2, Task 3: Turbine performance:

The figure and graphs below show the power curve for the Vestas V100-1.8MW turbine. It depicts the electrical output power in kW as a function of wind speed (m/s). Use the 60-Hz curve for the present application. The turbine operates between a cut in speed of 3m/s and a cut out speed at 20m/s.



Vestas

V100-1.8 MW
Facts and figures

POWER REGULATION pitch regulated with variable speed

OPERATING DATA

Rated power	1,800 kW (50 Hz) 1,815 kW (60 Hz)
Cut-in wind speed	3 m/s
Rated wind speed	12 m/s
Cut-out wind speed	20 m/s
Wind class	IEC S (IEC IIIA average wind/ IEC IIA extreme wind)
Operating temperature range	standard turbine: -20 °C to 40 °C low temperature turbine: -30 °C to 40 °C

SOUND POWER MODES

Mode 0: Max sound power level:	105.0 dB (A)
Mode 1: Max sound power level:	105.0 dB (A)*
Mode 2: Max sound power level:	103.0 dB (A)

*) low noise at low wind

ROTOR

Rotor diameter	100 m
Swept area	7,850 m²
Nominal revolutions	14.5 rpm
Operational interval	9.3 – 16.6 rpm
Air brake	full blade feathering with 3 pitch cylinders

ELECTRICAL

Frequency	50/60 Hz
Generator type	4-pole (50 Hz)/6-pole (60 Hz) doubly fed generator, slip rings

GEARBOX

Type	one planetary stage and two helical stages

TOWER

Type	tubular steel tower
Hub heights	80 m and 95 m

BLADE DIMENSIONS

Length	49 m
Max. chord	3.9 m

NACELLE DIMENSIONS

Height for transport	4 m
Height installed (incl. CoolerTop®)	5.4 m
Length	10.4 m
Width	3.4 m

HUB DIMENSIONS

Max. diameter	3.3 m
Max. width	4 m
Length	4.2 m

Max. weight per unit for transportation	70 metric tonnes

The table below lists material amounts and costs of a single wind tower of 95-m hub height, made of tubular steel. The foundation for each tower is a concrete disk or rectangular (16.76 x 16.76 x 3.04 m^3) plate, e.g., a design like the one given in the paper by A.N. Singh.

Quantities and costs of materials used in the construction of a wind tower of specified hub elevation.

Material \ System	Proposed (240ft)	Tubular steel (240ft)	Proposed (320ft)	Unit Cost
Concrete (yd^3)	600	---	880	$ 400
Prestressing strands (lb)	28,500	---	34,000	$ 1.50
Post-tensioning tendons (lb)	---	---	---	$ 2.30
Threaded Bars (ft)	300	---	400	$ 22.5
Reinforcement bars (lb)	50,800	---	73,500	$ 1.00
Structural Steel (lb)	---	614,700	---	$ 1.50
Material Cost	$ 340,000	$ 922,000	$ 486,000	

Note: The above estimates for use of construction concrete do not include the service roads connecting the towers of the wind farm and the electrical power lines. Estimates of associated materials and costs should be based on the final geometrical design of the wind farm, requiring numbers and spacings estimates to be made first (Task 4).