Due: Nov 30, 2023

Energy: Science, Technology, and Society

Project 2

Prospects for a 250-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 coventional power generation based mainly on coal 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 in 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. Retrieve the NOAA windspeed (v) data at the airport ROC in Rochester (NY) for the year 2022 as representative for the larger area. Generate the probability distribution $P(v) = \Delta N(v)/N\Delta v$ for the measured total number *N* of data points and appropriately chosen speed intervals (Δv). Produce graphs of relevant raw data.

3. **Calculate Single-Turbine Output:** Given the wind data obtained in 2) and the design specifications provided for a popular wind turbine, estimate the mean and fluctuating electrical power (capacity factor) generated by a single turbine. Use the performance data provided for the Vestas V100-1.8 turbine, i.e., the curve $Output_e(v)$ of electric output power vs. wind speed v. Assume the theoretical variation of windspeed with hub elevation.

a. Produce sample graphs of the daily power generated by one turbine during two periods during the year 2022, each 2-weeks long.
b. Present tabulated power data month by month and
c. the mean generated power, averaged over the entire year 2022.
d. Identify days in 2022 when the turbine rotor blades would have to be feathered because of high winds/storms?
e. In which months were wind speeds insufficient to generate power larger than 10% of nominal?
f. Calculate how many (N_t) wind towers are needed for a windfarm to generate a mean electrical power of 250MW, given the wind speed distribution in 2022.

4. **Site Layout:** Based on the results obtained in Task 3, conceive a wind farm with N_t wind towers in NW New York. The farm would be an array of N_t individual towers with 0.25 GW of **average delivered total power** at the wind conditions prevailing during the surveyed time period. Farm design criteria are 1. efficiency of turbine operations and 2. costs of cable connections and maintenance access pathways to all turbines. Assume land is leased and therefore requires no land acquisition capital.

   Design and sketch schematically a simple geometrical Cartesian pattern (☐) for the onshore site of a hypothetical windfarm. Assume wake-safe distances between turbines (10 x D_{rotor}, Betz Law).

   Consider the following land requirements:

   a) Allow an area of ¼ acre (☐) for the foundation of the base of each wind tower.
   b) Include paved access/service pathways (25′ width, 2′ foundation, \$17/cyard) to and between turbines.
   c) Allow one 25′-wide strip of land for underground power cables connecting each turbine to its transformer/converter substation.

5. **Construction & Connection Cost:** Estimate how much concrete and steel is needed for construction of the N_t towers. Use the information contained in the cited paper by A.N. Singh for a similar tower construction. Use \$1.5/W as cost for turbine, rotor and nacelle enclosures. Use \$0.50/foot for the power cable needed to connect the tower generators to a converter substation. Neglect costs for fiberoptics and wireless equipment for tower control and monitoring.

6. **Transformer/Converter Substations:** Each substation can collect electrical power output from 20 turbines. Each turbine output power needs one transformer (cost \$15k/turbine). The substation (construction cost \$3M) transforms and delivers the power via one high-voltage (12kV-69kV) power cable for long-distance transmission. Preferred location of a station is at the periphery of the wind farm.

7. **Capital Investment:** Estimate the capital installation cost for the wind towers and the environmental footprint of the farm. According to the U.S. Department of Agriculture's Land Values 2020 Summary, an acre of land costs \$3,100 on average. As an alternative, current local interest rates for a 20-year lease of farm land are \$125/acre per year.

8. **Bare Cost Estimate:** Estimate the power cost ($/kWh) assuming similar operational conditions (as in 2022) over the lifetime of the farm. The wind farm operation (1 technician per 10 towers) and maintenance costs amount to approximately $50/kWyear.

9. **Emissions:** Calculate the amount of cement 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 elifetime of the farm.

10. **Upgrade to Dispatchable Power:** To guarantee an available (dispatchable) total power level of P_{total} =0.25 GWe, the wind farm power output has occasionally to be supplemented by standby power provided by a local nat-gas-powered plant (0.25-GW_e nominal, base load). To be able to satisfy 0.25-GW_e spot demand, the backup plant must be running continuously at a minimum of 15% nominal power. Calculate the power cost of this combination (wind farm plus backup). Use local retail cost (6₵/kWh) for calculating the cost of backup electricity.

Project 2, Task 1 (Explanations/Hints):

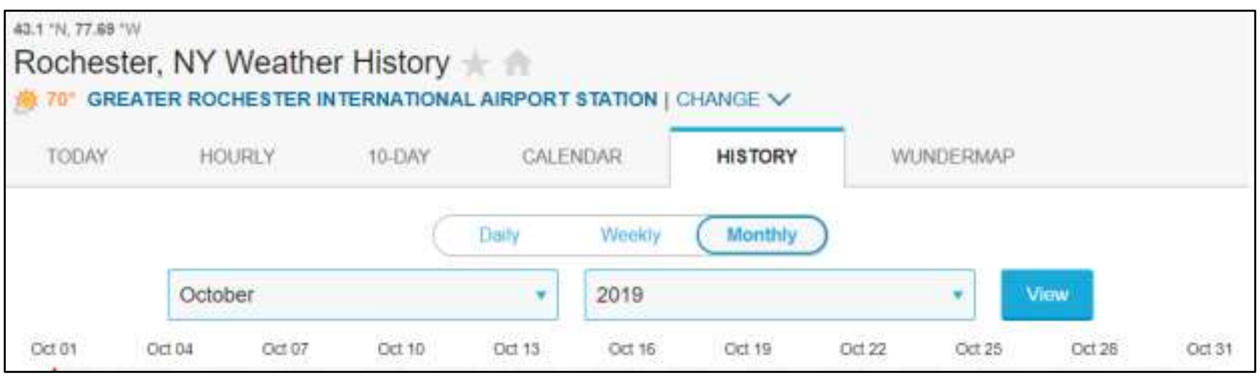
In preparation for the execution of Project 1, locate the web site below (or another official site) that posts hourly, daily, etc. numerical data for observations of wind speeds at the Rochester International Airport (ROC). Download numerical wind data from the site and insert them into a spreadsheet. Below are some screenshots from using the site.

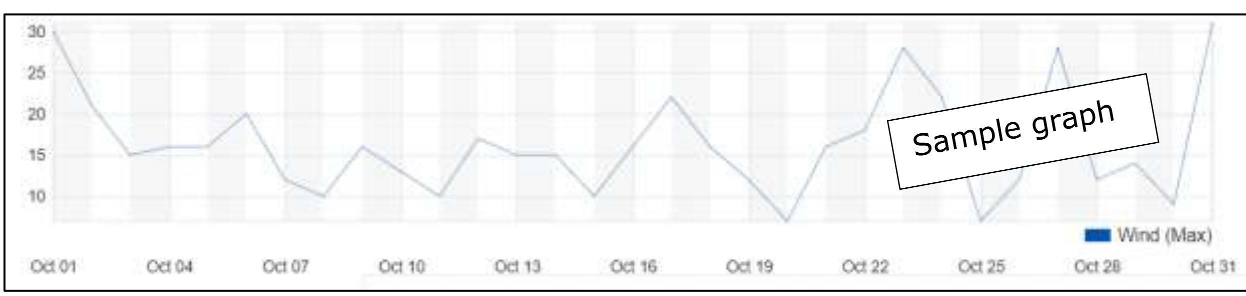
https://www.wunderground.com/history/monthly/us/ny/rochester/KROC/date/2019-10

Daily Observations

Time	Temperature (° F)			Dew Point (° F)			Humidity (%)			Wind Speed (mph)		
Oct	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	[illegible]	[illegible]
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

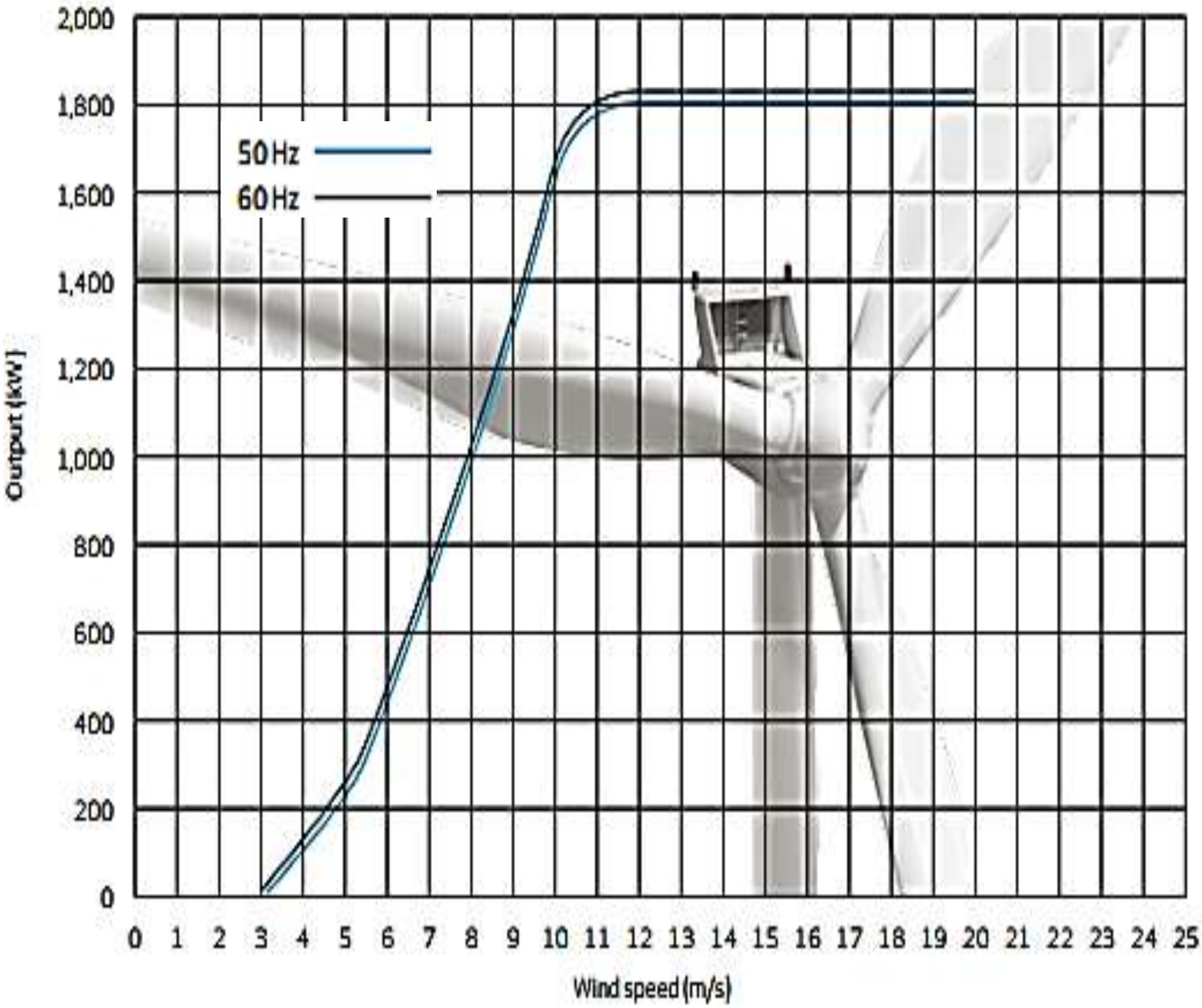




Given the wind speeds, as well as the specifications of the turbine type considered for the windfarm in the North-Western NY area, one can calculate the mean amount of electric power generated monthly by the farm and its fluctuations. The latter two quantities are to be derived from the wind speed observations at ROC. From this information, determine the number of turbines required to replace, ideally as completely as possible, the power P_{base}=0.2 GW_e generated by a conventional baseload power station.

Project 2, Turbine performance:

The figure below shows the performance of 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 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	Concrete structure
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 app. 100-m (330’) hub height, made of steel-reinforced concrete. The list does not include the concrete base needed for each tower in onshore construction. Use the base design by A.N. Singh (16.76 x 16.76 x 3.04 m^3) and scale prices in the table.

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).

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	