Journal of Physics Special Topics
An undergraduate physics journal

A1_1 Wind Power on Different Planets

C. Tang, L. Armitage, M. Alexander

Department of Physics and Astronomy, University of Leicester, Leicester, LE1 7RH

November 8, 2023

Abstract

Wind turbines provide clean energy from the rotation of the turbine's blades. We investigate a hypothetical wind turbine on each of the Solar System's planets and how each planet's atmosphere may affect the turbine's power output. We conclude Venus is the best option, if construction there was possible.

Introduction

To produce clean, renewable energy, wind turbines have been constructed all over the planet. These turbines produce power from flowing air moving the turbine's blades, which spins them around a generator via a motor. Environmental factors such as wind speed and mass density of the air affect how the turbines may spin. Instead of improving the mechanics of the turbine, what if we improve the environment? In this paper, we briefly explore the hypothetical power output of a wind turbine on the planets of the Solar System, and see how their differing atmospheres affect power output.

Method

The energy produced by a wind turbine is determined by the wind speed v, the density of air ρ_{air} and the length of the turbine's blades (thus the radius of the area they cover R). We calculate the electrical energy produced by the turbine using equation (3) and the astronomical data provided by NASA [1].

Equations

We start from the standard kinetic energy equation, $KE = \frac{1}{2}mv^2$. Here, m (kg) is the total mass of air flowing through the turbine in a time t (s), and v is the velocity of the air (m s^{-1}). We divide the kinetic energy by the total time t, to get the average power produced in Watts:

$$P_{average} = \frac{mv^2}{2t} \tag{1}$$

We convert the mass of air flowing through the wind turbine to the volume of air V (m^3) flowing through the wind turbine in time t by $m = \rho_{air}V$, where the mass density of the atmosphere is ρ_{air} (kg m^{-3}). Also, we can relate the volume flow rate of air to the turbine blade length R (m) with the following expressions:

$$\frac{V}{t} = Av = \pi R^2 v \tag{2}$$

where A (m^2) is the approximate cross-sectional area swept out by the wind turbine [2]. Substituting $V = \pi R^2 vt$ into mass gives $m = \rho_{air}\pi R^2 vt$. Substituting this into Equation (1) gives a final expression for the power,

$$P_{average} = \frac{1}{2}\rho_{air}\pi R^2 v^3 C_p \tag{3}$$

C_p is the rotor efficiency, it has been added to account for the conversion of energy [2].

Condition and Assumption

For our calculations, we set the wind turbine blades to 75 m long and set the wind velocity v to 7 m s^{-1} on all planets. As wind speed varies largely with location and time on each planet, each planet having its own average wind speed would not be appropriate for comparison. The rotor efficiency C_p is taken to be 30% [3].

Results and Discussion

Planets	Air density (kg/m^3)	Power generated (MW)
Mercury	N/A	N/A
Venus	65	59
Earth	1.217	1.11
Mars	0.02	0.02
Jupiter	0.16	0.15
Saturn	0.19	0.17
Uranus	0.42	0.38
Neptune	0.45	0.41

Table 1: List of air density of planets at pressure of 1 bar from NASA [1] and the resulting power produced on them (Mercury has been excluded due to having negligible atmosphere)

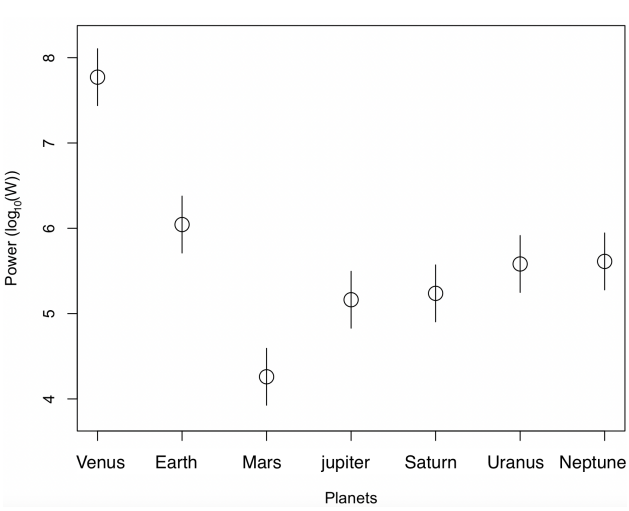

Figure 1: The log of power generated by wind turbine on different planets. Error bars are produced from the rotor efficiency range of 20%-40% [3].

The power generated from different planets will be different due to their air density ρ_{air}, which can be seen in Equation (3).

Figure 1 shows that with identical wind speed, a wind turbine on Venus produces the highest power output and Earth produces the second highest. The least effective is on Mars. This is because the air density of Venus is the largest among all planets while Mars only has a density of 0.02 kg/m^3 as shown by table 1.

From Figure 1, we can clearly see that Venus would be the best planet to generate energy from wind, if the only factor considered is density of air.

Conclusion

We conclude that Venus would be the best planet to generate electricity using wind power, but installing wind turbines on Venus would not be practical, due to the harsh weather and environment. The wind speed on Venus is very high, could reach up to 100 m s^{-1} [4]. Although a lot of energy could be produced, the turbine would be severely damaged due to the wind speed. Repairing any damage on a turbine would be very difficult, and the energy produced for this will most likely outweigh any energy generated. It is unlikely that a traditional wind turbine would operate at its maximum possible efficiency. Earth remains as the second best place to use wind power, as its atmospheric density is the second largest. Although there would be significantly lower damage to the turbine, the power produced would be much lower.

References

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