Contribution ID : **70** Type : **Poster**

Estimating the Exploitable Wind Power of a 4.5 MW Wind Turbine via Computational Modeling in MATLAB and Python: A Betz-Limit Approach

Electricity generation from fossil fuels is a major source of air pollution and greenhouse gases, contributing to respiratory and cardiovascular disease. Wind energy offers a low-impact renewable alternative, though its exploitation depends on fluid mechanics principles and physical conversion limits.

This work develops a MATLAB/Python model to estimate exploitable power and energy output of a commercial 4.5 MW turbine, integrating the wind power equation, the Betz limit ($C_{p,\max} = 16/27 \approx 0.593$), and a power curve with cut-in, rated, and cut-out speeds (3.0, 11.5, 25.0 m/s) per IEC 61400-1.

The methodology derives available power from continuity, Bernoulli, and energy conservation equations applied to a control volume around the rotor, then simulates turbine output under monthly wind speeds (annual mean 8 m/s).

Results confirm a cubic relationship between wind speed and power; the turbine reaches rated capacity (4.5 MW) in peak months (June–September) but drops sharply otherwise. Annual production is estimated at $17,708.09$ MWh, consistent with the Betz limit and power curve.

Computational modeling proves a reproducible, low-cost tool for preliminary wind assessment; combining fluid mechanics with real operational parameters yields more realistic estimates than theoretical models, supporting wind-project planning aimed at reducing emissions.

Keywords: wind energy, Betz limit, fluid mechanics, computational simulation, MATLAB, Python

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Session Classification : Física Aplicada y Computacional