e-ISSN: 2582-5208
International Research Journal of Modernization in Engineering Technology and Science
(Peer-Reviewed, Open Access, Fully Refereed International Journal)
Volume:06/Issue:04/April-2024 Impact Factor- 7.868 www.irjmets.com

A REVIEW OF MULTI ROTOR WIND TURBINE DESIGN AND COST SCALING

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DOI : https://www.doi.org/10.56726/IRJMETS51939

ABSTRACT

The current generation wind turbines are upscaled into multi megawatt range in terms of output power. However, the energy benefit from the turbine is offset by the increased mass and cost. Twenty MW wind turbines are now feasible with rotor diameters up to 200 m, according to a new report from the EU-funded UpWind project in 2022. The question is, how much bigger can wind turbines get realistically? One concept worth considering, and the one that is the subject of this thesis, is to have more than one rotor on a single support structure. Such turbines could have a greater power to weight ratio. Multi-rotor systems also offer the advantage of standardization, transportation and ease of installation and maintenance.

In this thesis the NREL 5 MW single rotor baseline wind turbine is compared with a 5 MW multi-rotor wind turbine. The multiple rotors are downscaled using scaling curves keeping the 5 MW baseline machine as reference.

Keywords: Wind Turbine, Multi Rotor, Co-Planer, Co-Axial, Counter Rotating.

I. INTRODUCTION

The increasing awareness of the need for environmentally sustainable energy pro- duction has driven the promotion of wind energy conversion systems. Wind is a form of solar power, created by the uneven heating of the Earth's surface. Wind turbines have been developed for over a millenium and are avalaible in various configurations of horizontal and vertical axis. Wind energy conversion systems tranform kinetic en- ergy avaialble in the wind into eletrical energy. Due to some favourable characteristcs such as economical viability, a clean energy resource, low environmental impact, and the potential to cover a large percentage of the energy requirement, this technology has grown considerably in the last few decades. Presently, wind energy accounts for 2.3% of the total U.S. electricity supply. The cost to produce a unit of electricity from the wind has decreased by 80% during the last twenty years.

Wind Power Around the World

Most modern horizontal axis wind turbines (HAWT) have the following principle subsystems as shown in: i) the rotor-nacelle assembly (RNA), ii) the support structure which includes the tower and the foundation, and iii) the electrical system including cables, transformers, switch gear etc. The RNA is mounted on the tower and has four main components: i) a rotor with two or three blades with a sup- porting hub to extract the flow energy from moving air and convert it into rotational energy in the shaft, ii) a transmission system to gear up the rotational speed of the shaft, usually consisting of shafts, gearbox, coupling, and a mechanical brake, iii) a generator to convert the mechanical energy into electrical energy, and iv) a controller to supervise the performance of the system.

Power Curve

The power output of a wind turbine varies with wind speed and every wind turbine has a characteristic power performance curve. With the curve it is possible to predict the energy production of a wind turbine without considering the technical details of its various components. The power curve gives the electrical power output as a function of the hub height wind speed. Shows an example of a power curve for a hypothetical wind turbine.

The performance of a given wind turbine relates to three key points on the velocity scale: i) cut-in speed which is the minimum wind speed at which the machine will deliver useful power, ii) rated wind speed at which the rated power is reached.

One-Dimensional Momentum Theory and Betz Limit

From momentum theory, it can be shown that the power of a cylinder of air of radius R and density ρ moving with a given speed v can be expressed as:

$$P = \frac{1}{w2} \rho\pi R2v3 \quad (1.1)$$

Since the air has to flow away from the wind turbine to be in a steady-state condition, the air stream cannot be stopped by the rotor. Thus, only a fraction of the kinetic energy available in the wind can be extracted. This fraction is referred to as the power coefficient, Cp of the wind turbine. The maximum value of Cp that can be achieved is 16 or 59.26% and this is called the Betz Limit. Therefore, the mechanical power extracted by a wind turbine of radius R from an air stream of speed v.

Parametric Sensitivity

It can be seen from that the extraditable power from the wind turbine varies as the square of the rotor radius R and as the cube of the wind velocity v. Thus the output of a wind turbine greatly depends on the choice of site (mean wind speed) and the size of turbine (rotor radius). Because the potential energy produced from the wind is directly proportional to the cube of the wind speed, increased wind speeds of only a few meters per second can produce a significantly larger amount of electricity. It should be noted that the Cp is not constant, so in reality most power curves are not purely cubic. In fact, real power curves are closer to linear in the range between cut-in and rated wind speed. The above case holds good for a given Cp at a given wind speed and rotor radius.

Merits and Drawbacks of MRWTs

In so far as multi-rotor wind turbines are so different from conventional wind turbines, it is worth summarizing what some of their anticipated advantages (merits) and disadvantages (drawbacks) are.

Merits:

- Reduced blade mass and cost since blade weight increases with diameter faster than power.
- Reduced total rotor-nacelle assembly (RNA) weight, possibly result in reduced tower weight and cost. Reduced RNA weight means reduced weight of the transmission-generator assembly as well as that of all the rotors.
- Greater average power due to the possibility to run the rotors at different (vari- able) speeds. Possibly increased average power output due to interaction of wake vortices of closely spaced turbines (discussed in Chapter 3).
- Ease of installation of smaller rotors.
- Ease of repair and maintenance of smaller components.
- Ease of transport of smaller blades. Smaller components are cheaper and easier to transport and assemble.
- 1 th turbine malfunction upon part failure for n rotor system. Realistically, this is feasible only if a turbine could be allowed to run with only some of its rotors operating (unbalanced forces would need to be considered).

Drawbacks:

- Increased mass of steel in tower top due to support frame to hold and yaw the multiple rotor assembly.
- Increased complexity of system overall.

II. CONCLUSION

The work presented so far shows how the different scaling techniques are integrated in scaling models such as the NREL and WindPACT studies to provide an overall model. This model helps in determining multi-megawatt wind turbine components' weights and costs. A three rotor wind turbine is designed to compare its cost and weight with a single rotor machine of equivalent capacity. The NREL 5 MW baseline wind turbine is used as reference for comparison. Scaling models downscale the 5 MW baseline machine RNA to three 1.67 MW capacity RNAs.

It has been shown that by using the scaling models the RNA components' weight reduces by ≈ 37% and cost reduces ≈ 25% . This is a promising result as the scaling model used is at a preliminary stage and is a crude version of the real situation. These are the preliminary numbers that we have arrived at. Keeping the tip speed ratio constant as scaling requires, the rotational speed of the rotor increases, decreasing torque and reducing load on transmission. Therefore nacelle components like gen- erator, gearbox, etc. will be much lighter than those components in a single rotor turbine, as shown in Table 3.3. The reduced component weight is offset by the sup- port structure weight. The triangular truss support structure described in Chapter 4 makes the tower top weight of the MRWT 5.13% heavier than the single-rotor ma- chine. Despite being heavier, it is 13.1% less expensive than the single rotor machine. The MRWT design is conservative and has great potential for optimization.

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