Blade Number and Overlap Ratio Efficiency Comparison in Savonius Wind Turbine Prototypes

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ABSTRACT Savonius wind turbines are a type of wind turbine whose rotor shaft and aerofoils are set perpendicular to the wind. From the reviewed literature, there is no clear consensus and even there are inconsistencies regarding the best characteristic on this type of turbines for a better efficiency regarding the number of blades and the overlap ratio among the blades, therefore, this study shades some light on the influence of the number of blades and the overlap ratio in their performance. For this purpose, several Savonius wind turbine prototypes were manufactured to study the effect of the number of blades and the overlap ration on the energy generation efficiency. The turbine variants consisted of two and three blades as well as with an 0.2-overlap ratio and without it. The performance consisted of measuring rotational speed and generated electrical power. All the results consistently showed that, in general, three-blade turbines with overlap ratio had better performance in contrast to similar turbines without overlap, or in comparison with two-blade turbines with or without overlap. For all turbines with the same number of blades, the overlap ratio showed about 22% better rotational speed performance than their similar without overlap ratio, thus evidencing that a 0.2-overlap ratio makes a difference. Three-blade turbines performed better than two-blade ones when both had or no overlap ratio. Similar conclusions were found consistent in terms of voltage and current outputs (generated electric power). And for the cases with similar performance output, two-blade turbines with an overlap ratio were preferable to three blades without overlap in terms of material saving, manufacturing time, and energy consumption.

KEYWORDS Renewable Energy, Wind Turbine, Efficiency, Savonius, Overlap Ratio.

1. INTRODUCTION

Renewable technologies are considered as clean sources of energy, and their optimal use reduces the environmental impact, produces minimum secondary waste, as well as are considered sustainable, based on current and future economic and social societal needs. However, renewable energies are often criticized for their unreliability. Nowadays, the storage and usage of stored energy are possible, for example, Tesla’s 7-kWh storage capacity home batteries, capable of powering several homes during the evening or providing energy to the utility grid during the day. Tesla's famous electric cars have a range of 400 km, with recharging times of 20 minutes [1]. The wind energy or solar energy may be an expensive source today, but in the long term, benefits will be understood, and they will become prevalent [1].

There are several types of wind turbines, and the most used ones are horizontal axis wind turbines (HAWT), vertical axis wind turbines (VAWT), and ducted wind turbines (DAWT). Horizontal wind turbines generally produce more electricity and are located on elevated sites, but they are noisy, and their maintenance costs are higher. Vertical wind turbines are usually placed on the ground level and generate lower energies in comparison with vertical turbines; they are more environmentally friendly; their relatively slower blade rotation is less harmful to animals and humans. Ducted type wind turbines use pressure difference as a working principle, they are located on buildings’ roofs [2].

Comparing both types of turbines VAWT and HAWT, even though HAWT's have better power generation efficiency (40% vs 35% of VAWT’s), VAWT require less rotation speed, less starting wind speed, are more resistant to wind, require less maintenance, are more resistant to failure; less noisy, do not require wind steering mechanism, and do not have cable stranding issues (less than 10 dB vs less than 60dB of HAWT's) [3], [4]. For this reason, a small VAWT prototype was designed and investigated for the scope of the present project. From the comparison of different VAWT types shown in Table 1 and Table 2, a proper vertical-axis turbine is the Savonius type because of its lower initial velocity, simplicity of blade design, and low noise in comparison with other turbine types.

Table 1
Types of vertical-axis wind turbines (part 1)

Factors	Darrieus [5]	Savonius [3]	Helical [6]
Power generation (efficiency)	2.3 kW (40%)	3 kW (35%)	4 kW (35%) [4]
Initial Velocity	2 m/s	2 m/s	2 m/s
Blade type	Eggbeater (D-Type)	S-type	Double helix
Blade materials (core coating)	Aluminum Alloy	Aluminum Alloy 3105	Aluminum or galvanized steel
Wind resistance	23 m/s	15 m/s	60 m/s
Failure rate	20 years	7 years	20 years
Maintenance	convenient	convenient	Convenient
Noise	0-8 dB	0-10 dB	0-50 dB

In VAWT, the number of blades and the overlap (OL) ratio are significant factors that influence the efficiency of the turbine [9], [10]. The overlap ratio is a ratio between the length of the blade and the gap between the blades.

Table 2
Types of vertical-axis wind turbines (part 2)

Factors	Solarwind [6]	Giromill or Noguchi [7]	Maglev [8]
Power generation (efficiency)	10 kW (50%)	2.5 kW (40%)	5 kW (32%)
Initial Velocity	2 m/s	3.7 m/s	1.5 m/s
Blade type	Double helix	H-type	Vertical blades
Blade materials (core coating)	Solar cells Coating: fluoro-polymer	Ayos wood Coating: NA	Turbine: Aluminum Magnet
Wind resistance	60 m/s	40 m/s	25 m/s
Failure rate	20 years	20-40 years	15 years
Maintenance	convenient	convenient	Convenient
Noise	~0 dB	Up to 50 dB	0-40 dB

There were some inconsistencies identified in the VAWT efficiency regarding the number of blades [9], [11], and the overlap [10], [12], therefore, this study focused on the investigation of the influence of the number of blades and the overlap ratio in the performance of the Savonius wind turbine.

2. METHODOLOGY AND DESIGN

The investigation strategy consisted of designing and manufacturing small Savonius turbine prototypes with two and three blades, both types with and without overlap ratio. Then, the turbines' performance was tested under similar working conditions to determine the best results in terms of revolutions per minute, voltage, and current output. For the case of blades with overlap ratio, an overlap ratio of 0.2 was chosen for the study following the recommendation in [10]. The mechanical design and solid mechanical simulation of the Savonius type wind turbine prototype was performed using SolidWorks. The blades, axis, and supports, were 3D-printed with a Ultimaker+2 using polylactic acid (PLA) plastic filaments due to its ecological and sustainable properties, and to its fabrication compatibility. To maximize the blade size, all turbines were built in three different parts: upper and lower bases, whose shafts connected a common frame with the blades through bearings. The top views of the designed blades can be seen in Fig. 1. There are two variants for the prototype with two circular blades: Without overlap ratio and with an overlap ratio or gap between the two blades. In the same fashion, there are two variants with three circular blades: Without overlap ratio and with an overlap ratio between the three blades. When constructing the turbines, there was no shaft, but the base and top were glued to the blades to avoid obstructing the overlap ratio.

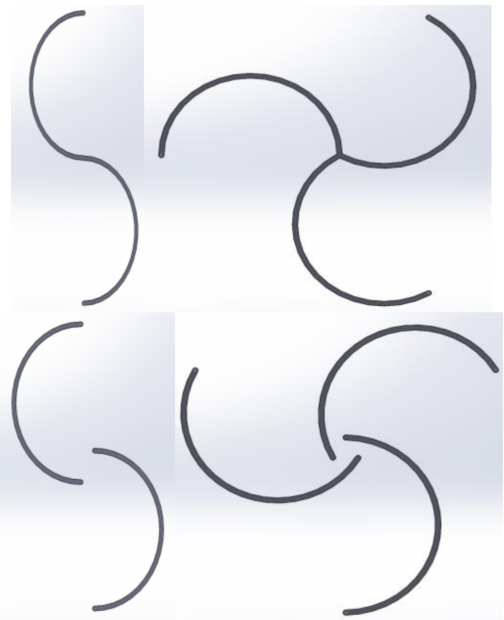

Figure 1. Blade models on SolidWorks.

In Fig. 2, the finalized 3D-printed and assembled Savonius wind turbines can be seen ready for being tested.

Figure 2. Four different blades.

Once all components were assembled, a proper motor selection was carried out, and the electrical circuit layout was proposed. Since a limitation was the student grant budget, and to simplify the design and reduce the number of components, it was decided to use a DC motor, since a brushless motor would require rectifier for charging electronic devices. The total cost of the materials and components was about 300 Euros, including PLA filament; bearings; DC motor Pololu 15783, 12V, 300mA, 500 rpm, 25mm shaft diameter; motor holder; cables; silicone gun with cartridges; SD card; drill machine tools; and glue.

3. EXPERIMENTAL SETUP, TESTING RESULTS, AND DISCUSSION

Once the blades and the mechanical complex have been mounted, the DC motor is installed on the holder of the frame housing, and a 1000-Ohm resistor is used as a load for measuring electric variables. Then, a vacuum cleaner in air blower mode for simulating stable wind conditions was used to rotate the blades and test their performance. Revolutions per minute (rpm), voltage and current values were measured for all prototypes under the same testing conditions. The experimental setup and its schematic are depicted in Fig. 3 and Fig. 4 respectively.

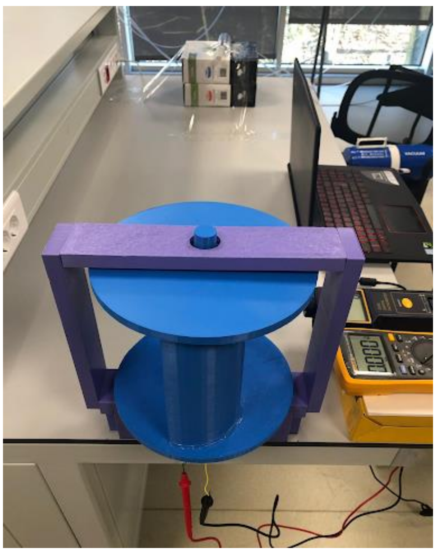

Figure 3. Experimental setup.

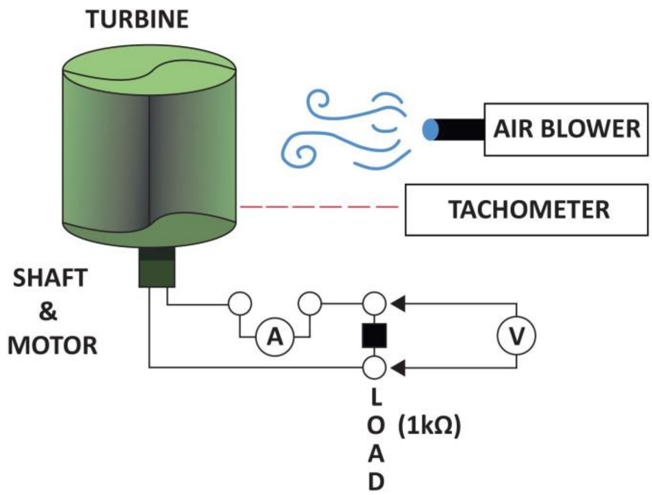

Figure 4. Schematics of the setup.

The testing procedure consisted of averaging twenty measurement values of revolutions per minute, voltage, and current, so to have consistent values. Bar plots in Fig. 5 and Fig. 6 show the experimental results, where 2B-NOL stands for two blades with no overlap ratio, 2B-OL for two blades with overlap ratio, 3B-NOL for three blades with no overlap ratio, and 3B-OL for three blades with overlap ratio. Notice that proportionality can be observed among the rpm, voltage, and current average values.

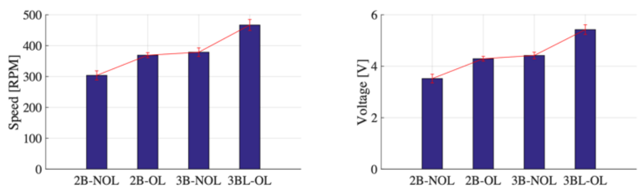

Figure 5. Averaged measurement values of revolutions per minute and voltage for different blades.

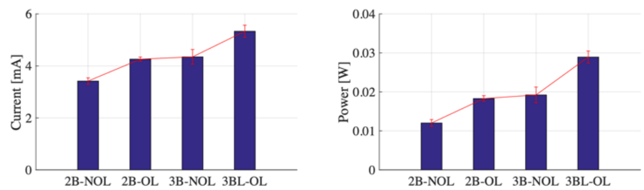

Figure 6. Averaged measurement values of current and power for different blades.

Table 2 summarizes average rpm, voltage, current and power values, consistently demonstrating that, in general, the best Savonius wind turbine performance in terms of energy generation for the same working conditions is the 3B-OL type with three blades and overlap ratio. Electrical power generation values are not considered in the table since they were indirectly obtained from their corresponding directly measured voltage and current values, therefore, the generated electric power can be considered directly proportional to these values.

Table 3
Performance comparison

Parameters	Two blades no overlap 2B-NOL	Two blades with overlap 3B-OL	Three blades no overlap 3B-NOL	Three blades with overlap 3B-OL
rpm [kW]	304 ± 15	369 ± 8	379 ± 14	467 ± 18
Voltage [V]	3.52 ± 0.17	4.29 ± 0.09	4.42 ± 0.13	5.42 ± 0.19
Current [A]	3.42 ± 0.12	4.26 ± 0.08	4.35 ± 0.28	5.33 ± 0.23

More detailed performance results that can be drawn from the testing results in Table 3 are the following:

1. According to all rpm, voltage and current tests, the wind turbine with three blades and 0.2 overlap ratio (3B-OL) showed better performance for given conditions, being 23.3% better than the one with the same number of blades but without overlap ratio (3B-NOL), and 26.5% better than with overlap ratio (2B-OL), which is even less massive (15% less material).
2. Comparing turbines with the same number of blades in terms of rpm, a turbine with overlap ratio (2B-OL) is 21.5% better than without overlap ratio (2B-NOL) for two-blades turbines, and a turbine with overlap ratio (3B-OL) is 23.3% better than without overlap ratio (3B-NOL) for three-blades turbines. Therefore, an overlap ratio of 0.2 makes a difference.
3. Comparing the rpm performance of having or not overlap ratio: A three-blade turbine with no overlap (3B-NOL) is 24.7% better that a two-blade turbine also without overlap (2B-NOL); a three-blade turbine with overlap (3B-OL) is 26.5% better that a two-blade turbine also with overlap (2B-OL).
4. The three previous conclusions are similar and consistent in terms of voltage and current outputs.
   For voltages:
   - 3B-OL is 22.6% > 3B-NOL, 3B-OL is 26.3% > 2B-OL, which is 15% less massive.
   - 2B-OL is 21.9% > 2B-NOL, 3B-OL is 22.6% > 3B-NOL.
   - 3B-NOL is 25.6% > 2B-NOL, 3B-OL is 26.3% > 2B-OL.

   For currents:
   - 3B-OL is 22.5% > 3B-NOL, 3B-OL is 25.1% > 2B-OL, which is 15% less massive.
   - 2B-OL is 24.6% > 2B-NOL, 3B-OL is 22.5% > 3B-NOL.
   - 3B-NOL is 27.2% > 2B-NOL, 3B-OL is 25.1% > 2B-OL.
5. Turbines with two blades and overlap ratio (2B-OL) produce almost the same output as those with three blades without overlap ratio (3B-NOL) in all output terms within up to 3% difference (2.6% for rpm, 3% for voltage, and 2.1% for current). Thus, for similar performance outputs, two-blade turbines are preferable to three blades without overlap, because they save 15% material, manufacturing time and energy consumption.

4. CONCLUSION

Different Savonius-type wind turbines with two and three blades, with and without 0.2-overlap ratio were designed and constructed, including their electrical subsystem. An experiment was conducted to test their output in terms of revolutions per minute, voltage and current delivery under the same conditions. All the results either in terms of revolutions per minute, voltage, current, and power, consistently showed that, in general, three-blade turbines with overlap ratio had about 25% better performance in comparison with similar turbines without overlap, or with two-blade turbines with or without overlap and that are 15% less massive. For all turbines with the same number of blades, overlap ratio showed about 22% better rpm performance than their similar without overlap ratio, thus evidencing that a 0.2-overlap ratio makes a difference. If evaluating rpm performance of turbines with no overlap ratio, three-blade turbines were about 25% better than two-blade ones; and in the case of turbines with overlap ratio: three-blade turbines were about 27% better than two-blade ones. Similar conclusions were found consistent in terms of voltage and current outputs (i.e., generated electric power). Turbines with two blades and overlap ratio produce almost the same output as those with three blades without overlap ratio in all output terms within up to 3% difference, meaning that for the cases with similar performance output, two-blade turbines with overlap ratio are preferable to three blades without overlap, because they save 15% material, manufacturing time and energy consumption. Since some researchers point out areas such as good performance under the weak and unstable wind, low noise, safety [13], modification of the rotor blade [14], and improvement of the coefficient of performance [11] as perspective fields for integration in urban areas, further research is planned on these areas.

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