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# COMPUTATIONAL FLUID DYNAMICS ANALYSIS OF FLOW AUGMENTATION SYSTEM APPLIED TO VERTICAL AXIS WIND TURBINES

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**Abstract:** Wind Energy, considered a stable alternative, may be implemented in cities by means of vertical axis wind turbines, which have better performance against turbulent flow compared to horizontal axis turbines. However, this type of turbine has not evolved technologically significantly in the last few centuries, being the horizontal axis turbines more studied and developed, due to the theoretical better efficiency of these turbines, which creates room for improvement. Therefore, vertical axis wind turbine will be studied and the performance of some enhancements will be analyzed aiming a more efficient harvesting of wind energy. In this regard, a flow augmentation system is proposed to be integrated with the wind turbine. In addition, the Lenz 2, S815 and JShaped airfoil shapes will be analyzed by Computational Fluid Dynamics – CFD technique on the ANSYS software for comparison of static torque generated by the wind turbine against wind flow for different angular positions of the turbine. Analyzing the gains obtained with the integration of the flow augmentation system proposed, achieving, this way, results regarding to cut in speed and overall efficiency of the shapes. Results show that the use of the convergent omnidirectional nozzle guide increased the overall static torque of all turbines, which would decrease the cut in speed, as well as its increased effectiveness on drag driven airfoils.

**Keywords**: Wind Energy; Convergent omnidirectional nozzle guide, Vertical Axis Wind Turbine.

## 1 INTRODUCTION.

Since the 1970s, oil crises have led several countries to seek to reduce dependence on imported fossil fuels and to increase security of supply of energy, thereby reducing the impacts caused by the seasonality of energy resources. The gradual replacement of oil by several renewable sources may be interpreted as an advantage because it minimizes supply risks and the negative impacts of supply shocks of dominant energy on the economy as a whole (Tagare, 2011). Environmental concerns, which have become more evident and discussed now, have become a major motivator in the search for cleaner alternatives to energy production.

Different sources of energy include biomass, solar, geothermal, hydroelectric and wind (Bhutta et al., 2012). Among these, wind energy has attracted significant attention during the last decades (GWEC, 2018), and has proven to be a cheaper alternative, resulting in extensive research to make wind power technology more efficient. The concept of using wind energy is based on the transformation of the kinetic energy contained in the wind into other forms of energy.

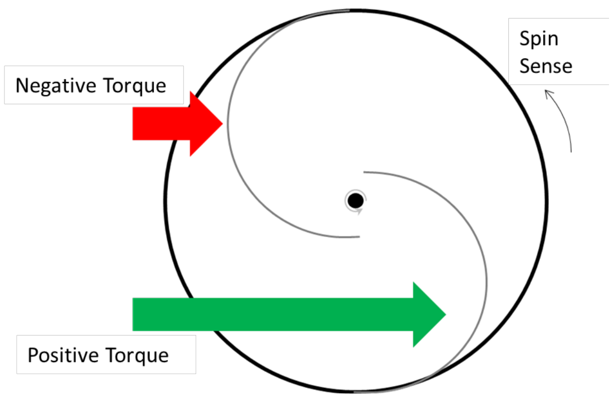
There are several types of wind turbines and these may be basically divided into Horizontal Axis Wind Turbines (HAWTs) and Vertical-Axis Wind Turbines (VAWTs). Vertical-axis turbines have some advantages over horizontal-axis turbines, such as not having the need of an active yaw mechanism and the fact that the power train and electrical equipment are at ground level, which facilitates its maintenance (Eriksson, Bernhoff and Leijon, 2008).

However, there are some disadvantages, such as theoretical lower efficiency compared to HAWTs, which reduced its use to very specific applications. This type of generator did not evolve technologically in a significant way in the last centuries, being those of the horizontal type more studied and developed. For this reason, VAWTs have not been given due to attention and have not been developed as the HAWTS, which creates room for their technological development and improvement. In recent years, there has been a further deepening in its study due to its possible application in urban spaces, having a better performance against the turbulent flow found in cities compared to horizontal axis turbines, in addition to a lower noise and visual impact (Rezaeiha, Montazeri and Blocken, 2019; Islam, Mekhilef and Saidur, 2013).

Researchers have been studying ways to improve the efficiency of vertical axis wind turbines by using different techniques to achieve this end (Elsakka et al., 2019; Marinić-Kragić, Vučina, and Milas, 2019; Zhu et al., 2019; Rezaeiha, Montazeri and Blocken, 2019; Saad et al., 2020). It has been determined some airfoil profiles that have a higher static torque than conventional ones, in order to improve the self-start capability (thus reducing the cut in speed, which is the necessary wind speed to start rotating the wind turbine), reducing the time it passes without generating energy and thus increasing the energy generated over time (Zamani et al., 2016; Sengupta, Biswas, and Gupta, 2016; Batista et al., 2016; Zwierzchowski et al., 2017).

Some studies have developed flow enhancement systems to increase the efficiency of vertical axis wind turbines (Wong et al., 2017). This flow enhancement system is able to increase the coefficient of power, hence improving the output power. It was used an obstacle in front of the flow to protect the blade that returns (against the movement) of the flow, thus reducing the negative torque in the axis that would be generated if there was no shield (Mohamed et al., 2010), as exemplified in Figure 1.

Figure 1: Negative torque generated without the use of proposed shield.




Source: Author.

A convergent nozzle was developed to direct the wind flow on the blade that generates positive torque on the shaft, increasing the overall performance of the wind turbine (Shikha, Bhatti and Kothari, 2003). However, the wind flow has no constant direction, so an obstacle or the convergent nozzle positioned arbitrarily around the wind turbine would not have the desired impact on a constant basis. It was proposed a system that consists of the union between the two ideas: an omnidirectional fin guide, which directs the wind and decreases the negative torque component generated by dragging the blades with opposite speed to the wind, facilitating the movement of the turbine, thus increasing the efficiency of the same (Chen, and Chen, 2015; Chong et al, 2013; Korprasertsak and Leephakpreeda, 2016). In order to quantitatively analyze the advantages and benefits offered by such systems, it is possible to use CFD-based simulations through software to predict the behavior of the integration of such systems with wind turbines (Chong et al, 2013; Korprasertsak and Leephakpreeda, 2016).

For the above, this paper simulates CFD-based wind turbine models with different airfoil profiles and flow augmentation systems, analyzing which of the profiles integrate more satisfactorily with such systems, thus determining a more efficient vertical axis wind turbine.

This paper is organized as follows. Section 2 briefly presents the technology of vertical axis wind tubines. In Section 3 the flow augmentation systems and the airfoil shapes are presented. Section 4 describes the methodology used in the tests made on CFD. The results and discussions are presented in Section 5. Section 6 shows the conclusions of this work.

## 2 VERTICAL AXIS WIND TURBINES.

There are several types of wind turbines, but usually they can be divided into Horizontal Axis Wind turbines (HAWT) and Vertical Axis Wind Turbines (VAWT). All over the world HAWT have been the main technology adopted by manufacturers, mainly because of its theoretical higher power coefficient and efficiency. Therefore, the research in this area was focused on this type of turbine and many advances have been achieved.

By the other hand, VAWT have some advantages such as simple structure, small operation space and less noise. These advantages have recently pushed up the investigation and improvement of this technology once it is more suitable for turbulent and inconsistent wind flow, which is the profile in urban areas. However, some drawbacks are still a challenge, one can cite, the difficulties on self-starting and the lower efficiency.

Among the vertical axis turbines, there are three basic types of technology: Darrieus, Savonius, and Giromill (Tong, 2020).

Savonius-type turbines are considered drag turbines, which generally combine a low aerodynamic efficiency with a high surface area. This large amount of material used translates into a high production cost compared to the limited production capacity. The drag driven devices appear to be limited to a prototype stage, and are primarily used for pumping water or other direct mechanical applications, considered not ideal for electricity generation, due to a low blade tip speed ratio and, consequently, a low power coefficient. One of the advantages of this type of turbine is the higher capacity to start turning itself (self-start capability) (Castelli and Benini, 2011).

Darrieus type turbines, considered as lift driven turbines, combine a high aerodynamic efficiency, close to the theoretical limit of Betz, with a much lower required blade area, depending on the blocking factor. Because they have a high blade speed ratio, this type of turbine does not require many coupled equipment, such as multipliers, thus reducing the weight of the system in general (Tong, 2020).

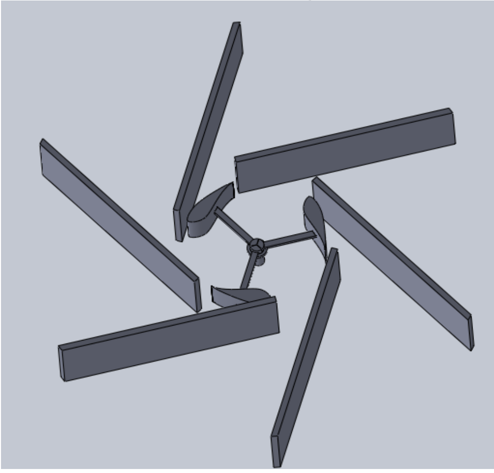
Darrieus type turbines may have different shapes of their airfoil in order to minimize or maximize some characteristic, compromising some other, besides having several configurations, as in H, delta, diamond, etc. This type of rotor has a low self-start capability, however, when starting to rotate, may reach high speeds and thus achieve high efficiency. Because of this deficiency at startup, they are generally not used alone, and starters are deployed to assist in their initial movement. Generally, it may be used together with a Savonius rotor, which will provide a good initial torque to remove the turbine from inertia, thus making use of the advantages of each type of turbine. Giromill type rotors are a variation of the "egg beater" Darrieus rotor.

## 3 ANALYSIS OF AIRFOIL SHAPES WITH FLOW AUGMENTATION SYSTEM.

In order to improve the efficiency of vertical axis wind turbines, it is proposed to use a convergent omnidirectional nozzle guide (CONG) around the rotor (Chen, and Chen, 2015), which is basically a set of panels placed around the rotor, whose purpose is to direct the flow directly to the blades, reducing the negative torque generated by the returning blades, and increasing the speed of the wind hitting the blades by means of area reduction. Figure 2 shows the proposed flow augmentation system that was simulated.

Three airfoil profiles are analyzed in this paper. They were chosen by means of literature review, aiming for profiles that had good self-start capabilities, as well as low negative drag coefficient. In other words, high positive drag coefficient, low negative drag coefficient and balanced lift coefficient (Sengupta, Biswas and Gupta, 2016). The vertical axis wind turbine is the same in all the simulations with exception to the airfoil profiles and the use of the convergent omnidirectional nozzle guide between simulations. The three profiles are: Lenz2, S815 and Jshaped.

Figure 2: The proposed convergent omnidirectional nozzle guide.



Source: Author.

The Lenz2, shown in Figure 3, is an airfoil profile that is considered a drag and lift profile, because it uses both drag and lift force to generate positive torque. Because of this feature, it is expected to have a low cut in speed, as well as a fairly high maximum speed.

The S815 profile is essentially a lift profile, because it uses lift force to generate positive torque. However, because it has some camber in it, it uses a little bit of drag force too to start the movement of the wind turbine, as can be seen in Figure 4. That use of drag force to generate more static torque reduces the cut in speed, which is very important (Sengupta, Biswas and Gupta, 2016).

Figure 3: Lenz2 profile on the simulated turbine.

Source: Author.

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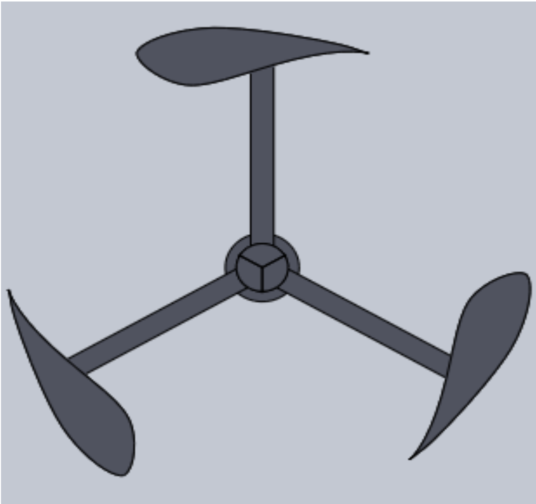
Figure 4: S815 profile on the simulated turbine.



Source: Author.

Jshaped is a profile that is basically a combination between the two profiles previously shown: it has a "shell" that drives the turbine using the drag force (like Lenz2), and also has an aerodynamic shape that generates lift forces such as S815 (Zamani et al., 2016), as shown in Figure 5.

Figure 5: Jshaped profile on the simulated turbine.

Source: Author.

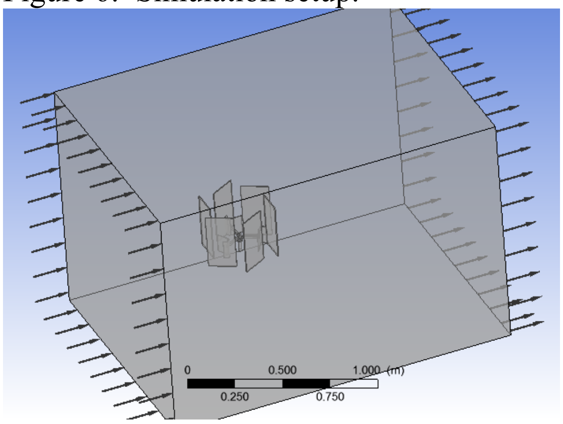
This format basically consists of a profile NACA 0015 with its upper portion removed, thus making the turbine have a better self-start capability, and still having good aerodynamics compared to the original profile NACA 0015.

## 4 METHODOLOGY.

The simulations were done in the CFD component of the Ansys 18.0 software, student version, with 731185 triangular elements with specific inflation conditions near curvature being applied, which increase the number of elements in the turbine area for greater precision in the calculations.

The simulations were performed at permanent regime, considering a wind input at 10 m/s (25 ºC), output at atmospheric pressure as may be seen in Figure 6, k-Epsilon turbulence model, mesh convergence test with 8% uncertainty, no slip boundary conditions at the turbine surface. In all the setups, the main body of the turbine had a diameter of 125 mm. As for the airfoil profiles, all three of them had a chord and height of 100 mm.

Figure 6: Simulation setup.



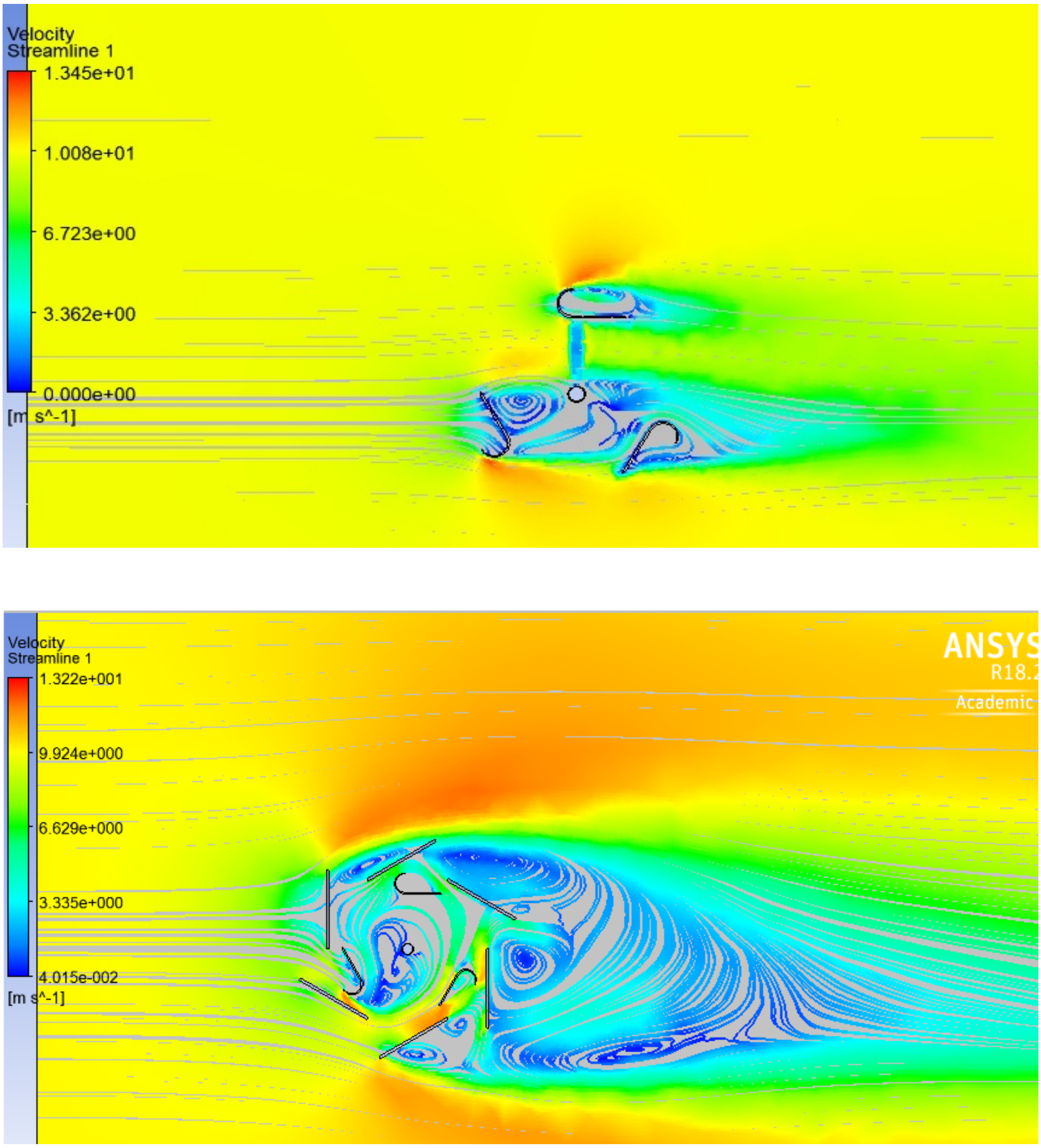

Source: Author.

The wind turbine was rotated into seven different positions: 0º; 20º; 40º; 60º; 80º; 100º and 120º. The first and seventh positions are equal, because the turbine has three blades and 120º represents one third of a turn, and the results for one complete turn are obtained simply by overlaying the results for 120º three times. In each of those positions, the static torque was calculated on the axis of the turbine, with and without the flow augmentation system, for the three airfoil shapes. In Figure 2 and Figure 4, it is shown the wind turbine with the S815 airfoil, with and without the flow augmentation system.

## 5 RESULTS AND DISCUSSION.

The use of the CONG resulted in a better guiding of the airflow lines to the wind turbine blades that generate positive torque, as well as avoiding or decreasing the amount that goes against the returning blades, which would generate negative torque, decreasing the efficiency of the turbine. This effect may be observed in Figure 7.

Figure 7: Guiding of flow lines (a) without and (b) with the use of the CONG.




Source: Author.

With this better flow line orientation, it was expected that the cut in speed of the wind turbine would be reduced, as demonstrated by the results of the simulation shown in section 5.2.

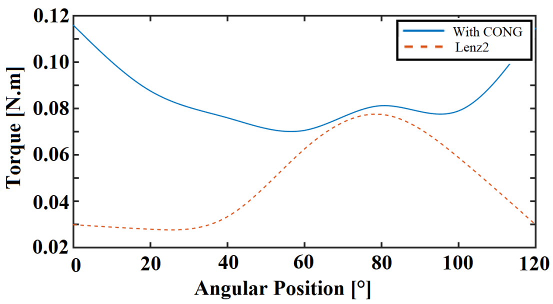
5.2 STARTING TORQUE IMPROVEMENT.

The simulations show that there was an increase in relation to the static torque of the wind turbine with the use of the flow augmentation system for all the chosen airfoil profiles.

**5.2.1 Lenz 2.**

It can be seen in Figure 8 that, with the use of the CONG, there was an increase in static torque. Calculating the work generated by this torque in a third of a turn, there is an increase of 72% in relation to the turbine without the system.

Figure 8. Static torque for different angular positions – Lenz2.



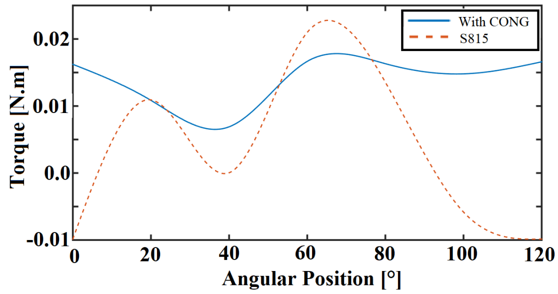

Source: Author.

In addition, there is less torque fluctuation over a third of a turn, which means less load fluctuation on the turbine shaft, thus reducing stress caused by fatigue.

**5.2.2 S815.**

For the S815 profile, an increase in static torque was also noted with the use of the convergent nozzle guide, and a 150% increase in the work generated by that torque was achieved by a third of a turn. It is also possible to notice a great smoothing in the torque variation, in Figure 9.

Figure 9: Static torque for different angular positions – S815.



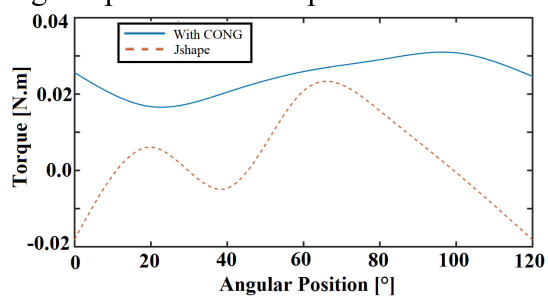

Source: Author.

Furthermore, without the use of the proposed system, we can see bands where the torque is negative, which would mean that the turbine would not rotate. With the integration with the system, the static torque becomes positive, which indicates that the turbine would rotate, regardless of the initial position of the turbine.

**5.2.3 Jshaped.**

The integration of the flow augmentation system with the Jshaped profile also showed an increase of the static torque and a decrease of the variation of the same, as can be seen in Figure 10. The increase in work generated by this torque was 520%.

Figure 10: Static torque for different angular positions – Jshaped.




Source: Author.

Like the S815, the integration of the CONG with the vertical axis wind turbine ensured, according to Figure 10, that the turbine would rotate independently of the initial position in which it is.

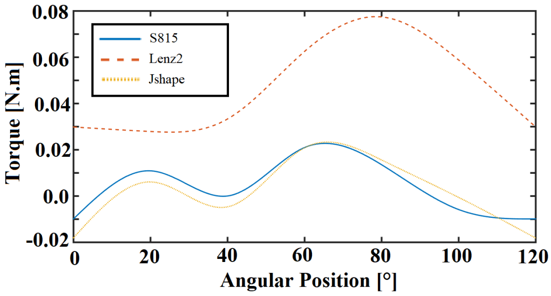
It should be verified that the highest percentage gain of static torque due to the use of CONG was in the Jshaped profile, increasing it by 520%. It is also noted that the Lenz2 configuration presents absolute static torque values superior to the other configurations, using or not the CONG, for all angular positions, i.e., it is the most efficient profile.

It should be noted that the highest percentage gain in static torque due to the use of CONG was in the Jshaped profile, increasing it by 520%. It is also noted that the Lenz2 configuration presents absolute static torque values higher than the other configurations, whether or not using CONG, for all angular positions.

## 5.3 TORQUE COMPARISON BETWEEN DIFFERENT AIRFOILS AND FLOW AUGMENTATION SYSTEM.

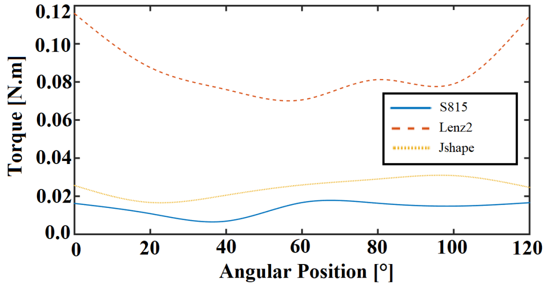
Analyzing Figures 11 and 12, it is possible to notice that, with the integration of the CONG, there was an increase of the static torque for all the profiles, besides a decrease in the fluctuation of the same torque over a third of a turn.

Figure 11: Static torque of the turbines without CONG.




Source: Author.

Figure 12: Static torque of the turbines with CONG.




Source: Author.

Prior to the use of the flow enhancement system, the work generated by the S815 profile torque was 36% higher than the Jshaped torque. Already with the use of the system, this was reversed and the work generated by the Jshaped profile was 81% larger than the S815. This demonstrates that the CONG has a greater effectiveness with profiles that use drag force to generate positive torque, which is the case of the Jshaped and Lenz2 profile.

## 6 CONCLUSIONS

Simulations of a convergent omnidirectional nozzle guide integrated to a vertical axis wind turbine, applying different airfoil profiles, showed that its use with a turbine generates an increase in the static torque of the turbine for all the profiles, which refers to a lower cut speed in and theoretically a higher efficiency of the turbine as a whole. In addition, results show that this flow enhancement system is more effective if used with airfoil profiles that use drag force to generate positive torque, such as the Jshaped and Lenz2 profiles.

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