VAWT report for Design of Fluid Machines for Clean Power Generation 2018

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Contents

Chapter 1

Introduction

The aim of this project is a preliminary design of a H-Shaped turbine using the *Double Multiple Stream Tube theory* (**DMST**) applied to finite elementary volumes.
In order to reduce the computational time of the code we have decided to use an array syntax, in this way for every "while" cycle the code will provide all the characteristics of half of the complete rotation.

Chapter 2

Calculations

2.1 Attack angle variation

The variation of attack angle of the profile is connected to the blade position along the circumference. In particular, it will be zero at 0° and 180° because the wind velocity is parallel to the peripheral speed. Also, there is a sharp increase from the downstream to windward part, because the profile is starting to face the wind, increasing its relative velocity. In the upstream part the profile will reach the maximum lift coefficient and then it will start to decrease: moving from up stream to leeward position the tangential velocity will change its direction following the wind one, so the attack angle will start to drop down until it reaches zero at180°.

2.2 Reynolds Number

Also, Re will follow the attack angle trend. It will reach the maximum in 0° because the tangential velocity is completely opposite to the wind one and so the relative velocity will result as the sum of them.
On the other hand, at 180° the two velocities have the same direction, so the relative one is the difference, thus Re will reach the minimum value. Due to this in the leeward region there will be the probability of stall condition.

2.3 Induction Factor

The induction factor is the portion of wind velocity lost before reaching the blade.
In DMST there are two different actuator disks: the *upwind* and the *down-*

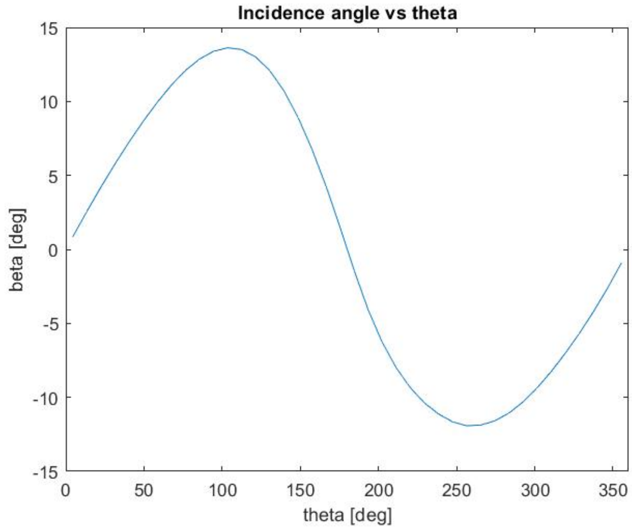


Figure 2.1: Incidence angle β as function of the angular coordinate θ.

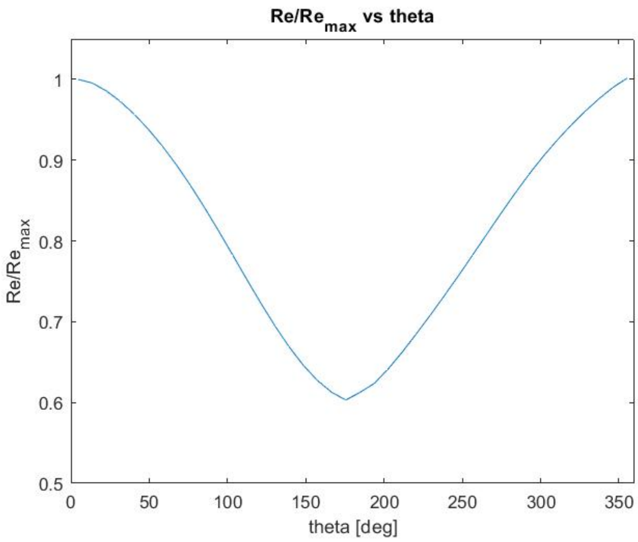


Figure 2.2: Variation of Re as function of θ.

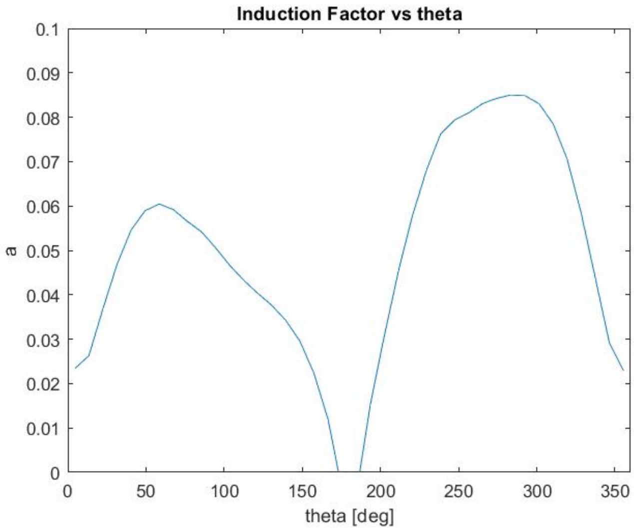


Figure 2.3: Induction factor a as function of θ.

wind. The trends are quite similar but the second one has higher values due to the stream expansion induced by the first one. In fact, the second disk will exploit only a portion of the incoming wind flow due to the conservation equation.
There are also other effects to be considered like the presence of the blades upstream, the struts, the shaft and the incomplete full wake condition.

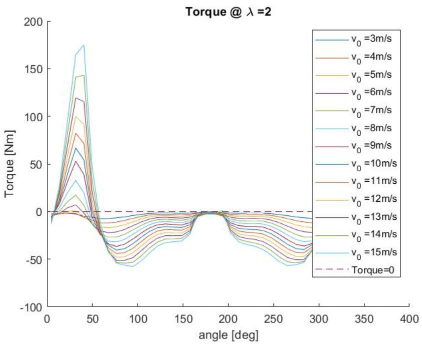
2.4 Torque analysis

To estimate the power produced by the turbine, it is necessary to evaluate the torque. To evaluate the tangential component of blades motion, a projection on θ and β is needed. The trend so is connected at first to β, because it's the first parameter which influences the aerodynamic force coefficient. The attack angle, as already said, will increase from downstream to windward section, from negative to positive values, also changing the lift coefficient, promoting a steep increase of torque, before reaching the flag condition at $0°$, when the lift is completely null, and no tangential forces are generated.
After this condition, lift starts to increase again: the windward zone represent the most efficient part of the profile, according to this, torque will reach its highest values in this region, in particular around $90°$. But the problem is at the beginning of the leeward zone. Here the attack angle will change its sign: now only the Reynolds number is the parameter useful to understand if the profile will reach the stall condition. In this phase, when tip speed ratio

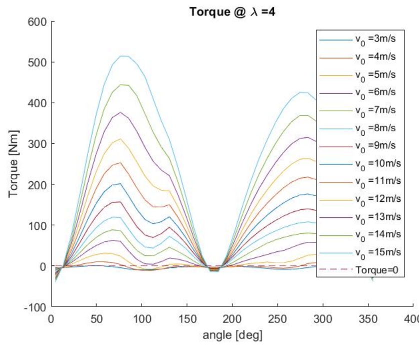
is significantly reduced (slow machine) the relative velocity will result very low, like the Reynolds number associated. For this reason, the wind flux has not sufficient energy to cross the profile length, causing the detachment of the veins and reaching the Stall (for vary small values of tip speed ratio, also before 90° the Stall is reached). In graphs is clearly evident how sharp is the loss of torque in this region, keeping also negative values that is to say that the machines is not able to provide torque but its needed to keep motion survive to drag forces.
Near the flag position at 180°, anyhow, the attack angle will be reduced a lot, letting the profile to regain efficiency and also positive Torque: the effect is very small, but it's present in the trends. On the other hand, for higher values of tip speed ratio, Reynolds number provides a good condition to the profile, keeping high the tangential component and also the relative velocity: in this way Stall will be not reached and a completely symmetrical trend of torque is reported in the graphs 2.4.
It is important to underline that for very high values of tip speed ratio, the tangential component will prevail in the velocity triangles, keeping the attack angles very small and avoiding a full development of the profiles: so lift will always remain very low along the circumference, reducing the torque and also the power generated. Torque is correlated to wind velocity, in fact when it increases the attack angles will become bigger, in this way the profiles work in a more favourable aerodynamic condition and at higher Re. Lift and drag coefficients are non-dimensional parameters, so when the theoretical wind thrust increases, also the forces will be affected.

2.5 C_P trend

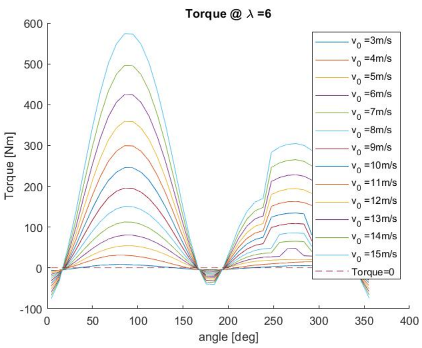
It is important also to consider the Coefficient of Power, which is strictly connected to the torque trend. The mesh displayed has the x-axis which is the variation of wind velocity incoming, with reasonable values; the y-axis which is the variation of tip speed ratio, which can be fixed for a big machine directly connected to the grid or variable for small machine coupled with an inverter. Moreover, the mesh shows how different combinations of these parameters affect the Cp trend in different conditions. Once again, the low value of torque is also showed in the trend, where C_P penalisation over torque is clearly reported, showing how it will not reach significant values, remaining close to zero. When the tangential component is sufficient to have a good Reynolds number and attack angle values, the C_P sharply increase, reaching a maximum value around 0,51. Then after this phase, the problem due to high attack angle limitation values due to high tangential component



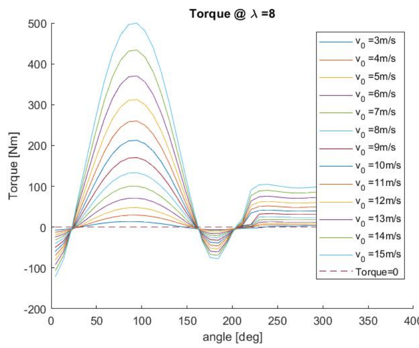
(a) Torque as function of θ at $\lambda = 2$



(b) Torque as function of θ at $\lambda = 4$



(c) Torque as function of θ at $\lambda = 6$



(d) Torque as function of θ at $\lambda = 8$

Figure 2.4: Torque variation

will occur, reducing the C_P.
Velocity of wind is very detrimental for performances when it's very low, for example at the start up of the machine, but then, when the profiles will reach a good interaction with the flux, only a small increase is showed. So it is clear that the wind velocity will always lead to an increase of the C_P of the machine if coupled to proper values of λ. However, λ can not be increased without any constraints, or the tangential component will reduce too much the attack angle and the torque. Wind velocity is also very important to evaluate the axial forces and so to properly design the structure of the turbine.

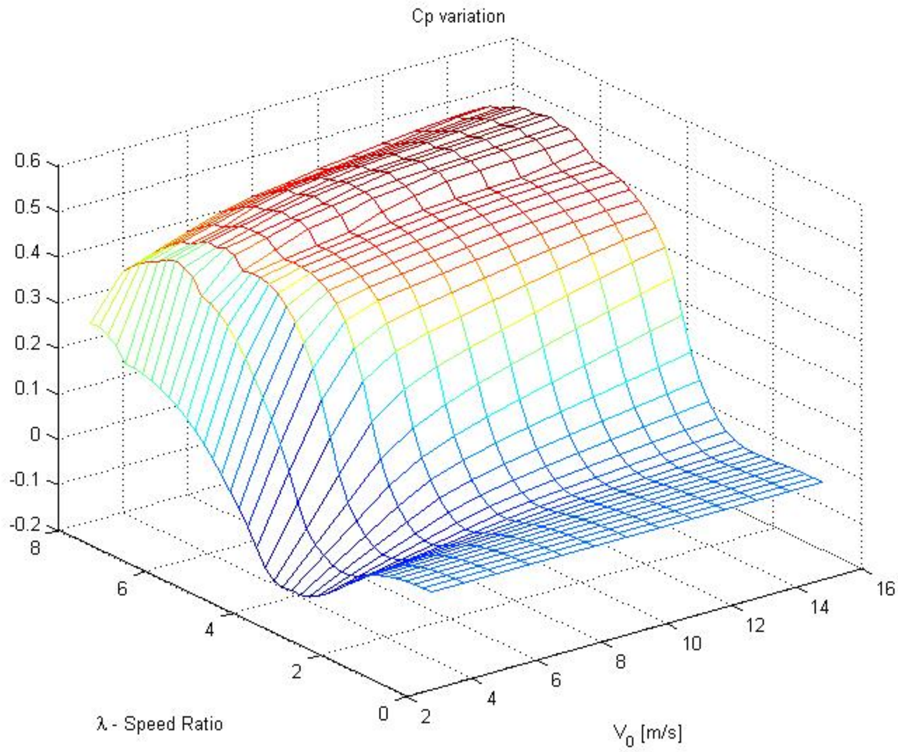
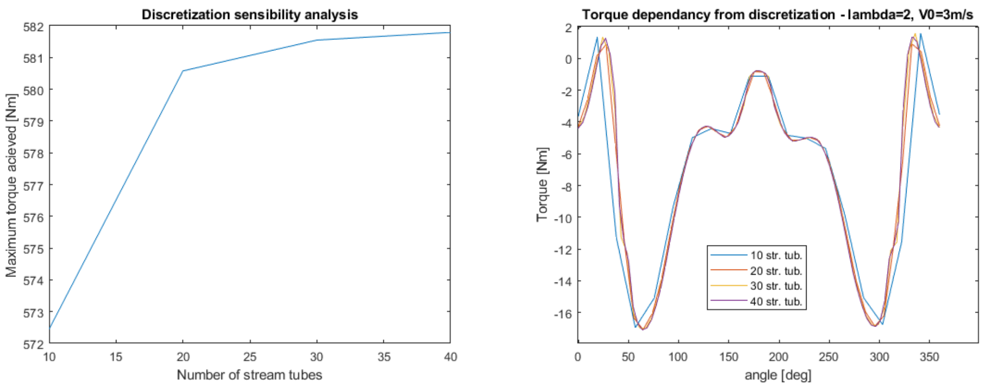


Figure 2.5: C_P as a function of λ and V_0.

Chapter 3

Discretization sensibility analysis

In our first calculation we have considered twenty stream tubes dividing the circumference in equal parts (so each stream tube has a different width: thinner at the extremities and larger at the centre). In Figure (3.1a) it is possible to see the variation of a reference quantity (the maximum achieved torque) when the number of stream tubes change from 10 to 40. We can see how, after 30 stream tubes, convergence is reached [1]. In Figure (3.1b) it is possible to appreciate the different evaluation of the torque curve in the same range of discretization for a sample case ($\lambda = 2$ and $V_0 = 3m/s$).



(a) The maximum torque achieved was taken as a reference for a sensibility analysis to the number of stream tubes.

(b) Same case evaluated with 4 different quantities of stream tubes. The roughness of the fiste case is relevant respect with the other three.

Figure 3.1: Discretization sensibility

[1] Torque(N_{st} = 20)=580,58 Nm; Torque(N_{st} = 30)=581,55 Nm; Torque(N_{st} = 40)=581,79 Nm)

Chapter 4

Conclusions

In the end, from this analysis, it is possible to say that a VAWT can compete with HAWT in some range of applications, but its modelling is harder, because there are several effects that can not be easily implemented in a design code. Effects like dynamic stall reached in leeward zone or the losses introduced by the presence of struts or the not completely far wake state at the incoming velocity for the second actuator disk. There are several activities in research in order to establish a relation to be easily implemented in a code. Another point is that there are no limits to λ in this studio: in HAWT the tip speed ratio has to be fixed in order to avoid mechanical problems in blades; in this case also it's reasonable to think to a possible maximum λ for structural reasons or that can introduce vibrations.
These machines are very interesting for an urban application, where at low wind speed, with a reasonable λ, is possible to reach a good C_P value, with a small structure instead putting a very large rotor design like a HAWT, with all problems associated. In future, probably, a great number of these VAWT will be installed, to gain power from wind where the classical and well design HAWT can not be used.