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Wake Patterns and Noise in a Dual Rotor Wind Turbine

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Summary

The complex flow in a dual-rotor, horizontal-axis wind turbine and its effect on noise generation is investigated. The case is studied using computational fluid dynamics as well as wind tunnel testing. The idea behind this design is to continue to extract more mechanical energy from the wind stream which has already passed through the first frontal rotor by having a second identical rotor on the other side of the main shaft of the windmill. The design is a modification to the existing commercial 3-bladed single rotor wind turbines used in windmill farms. The current design nearly doubles the electric power output generated from a similar single rotor windmill but at the expense of increasing the noise generated by the evolving wakes. The wake from each blade in the first rotor passes through the spacing between each two rear rotor blades while the undisturbed wind stream is intercepted by the rear rotor blades thus generating another wake system which is responsible for the increased noise level from the turbine. The strength and pattern of the wakes are determined for low and high wind speeds which are correlated to the noise generation. A small scale model was also built and tested in a subsonic wind tunnel.

1.Introduction It is well known in the art that wind turbines convert wind energy into electrical energy but they are known for their relatively low efficiency. Thus, there are some conventional solutions that enhance the efficiency and performance of these turbines. Among these conventional solutions found in the literature is a machine for converting wind energy into electrical energy comprising in combination a housing; propellers at the forward and rearward ends of the housing mounted on shafts for rotation upon a common horizontal axis of rotation; post means supporting a central extent of the housing for rotation in a horizontal plane to face into the wind; an alternator within the housing formed of a power take off member coupled to one shaft and a rotor coupled to another shaft for counter rotating when the propellers rotate for thereby generating electricity; centrifugal pitch control mechanisms for varying the pitch of the propellers as a function of the propeller speed; transmission mechanisms for varying the speed of rotation of the rotor and power take off member as a function of the wind speed; brake mechanisms for proportionately restraining the propellers against rotation; and an aero governor operatively coupled with the brake mechanisms for control thereof in response to the speed of the wind as determined by the aero governor [McComb].

Another conventional solution discloses a wind turbine having first and second rotors mounted on a common horizontal axis on a tower. The rotors rotate in the same direction and drive an electrical generator by a fluid or belt. Alternatively, the electrical generator may be positioned between the rotors, at the top of the tower. Means that determine the wind direction and strength, to enable a shaft to be rotated about an upright axis (the tower) so the rotors face the wind. The rotors have blades, the blades of the front rotor being shorter than the rear blades by up to 75% [Treadwell].

In another conventional solution, there is provided a dual rotor wind turbine according to the present invention including a rotatable drive shaft, a first rotor assembly connected to the drive shaft, a second independently-rotating rotor assembly coupled to the drive shaft rearward of the first rotor assembly, a first stage generator coupled to the drive shaft, a second stage generator operatively connected to the second rotor assembly, a housing wherein the generators are situated, a rotary base, and a tail. In use, the rotary base allows the tail to optimally position the rotors for collecting wind.

Wind rotates the first rotor assembly, causing the drive shaft to rotate and operate the first stage generator. Wind passing through and directed off the first rotor assembly rotates the second rotor assembly, independent of the first rotor assembly, operating the second stage generator [Miller].

The above conventional solutions do not have high efficiencies since the rear rotors lie in the wake of the first rotor, and thus the rear rotors are being counterproductive. For this reason, there should be provided an adjustable dual rotor wind turbine in which the relative angular displacement between the front and rear rotor blades is automatically adjusted to prevent the rear rotor from harvesting any counterproductive wake of the first rotor and receive only the free undisturbed stream of wind and thus increases the output power of the whole unit [Asfar].

2.Description of the Device

The proposed wind turbine unit under investigation is a horizontal axis wind turbine which has adjustable and rotatable dual rotors. This unit will have increased and optimum power efficiency. As shown in Fig. 1, the unit consists of a tower, two similar rotors having identical blades, two shafts, a gearbox, a swivel joint, and a means for adjusting the relative angular position between the two rotors.

The rotors are positioned opposite to each other and are separated by the central unit housing the gear box, generator and control circuit. Each rotor has its own shaft which has a common axis. The two shafts may be coupled together by a simple clutch. The common shaft drives the gear box which in turn drives the generator.

The clutching mechanism engages and disengages automatically such that the rotors are free to rotate relative to each other when the clutches are disengaged. The clutch engages and disengages while searching for the best angular position of the rear rotor relative to the front rotor for a given wind speed. The combined generated power is measured when the two rotors are engaged through the clutch and the measured value is taken as basis for the decision to stay engaged if the power is maximum.

3.Experimental Work

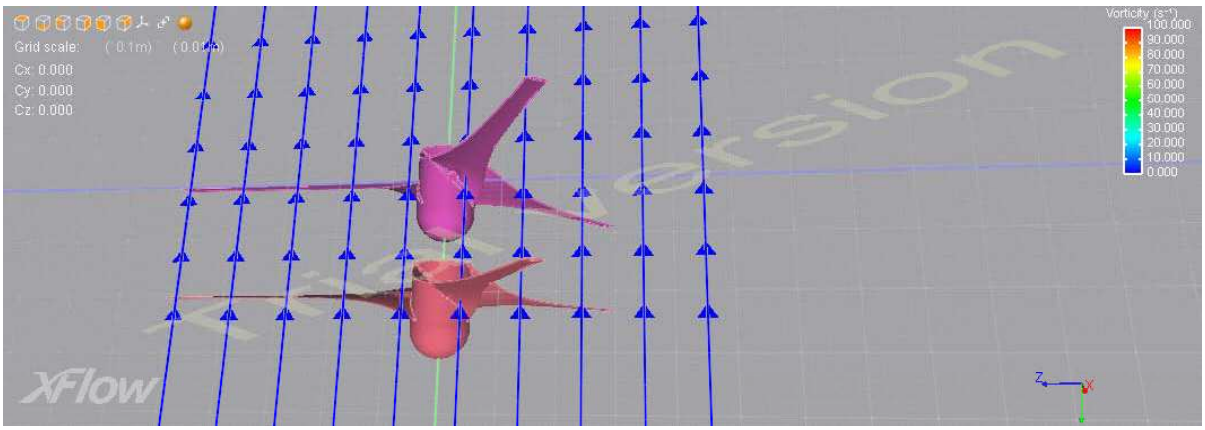
A small scale model was built and tested in the subsonic wind tunnel in the Aerodynamics lab at Jordan University of Science and Technology (see Fig. 1) for verification of the proposed concept. The wind tunnel test section is 60x60 cm and has a variable fan motor speed with a maximum air speed of 22 m/sec. It has a Pitot tube and a turbine wheel air speed measurement with digital readout including air temperature. Two identical 3-bladed rotors were used each having a 27 cm diameter. The rotors are mounted on one threaded 9-mm shaft which is coupled to a permanent magnet 12-volt electric generator on the far end of the same shaft downstream. This arrangement was chosen in order to minimize the effect of the wake of the relatively large size of the generator as compared to the rotor size if it was located between the two rotors. A 12-volt small light bulb (45 Watts) was used as the resistance load to absorb the generated power. The tower placed the rotor shaft in the middle of the test section with a height of 30 cm. Ambient temperature and pressure conditions were recorded as 25 Celsius and 75.8 cm Hg.

Testing started with only the front rotor attached to the generator shaft as a reference point for all measurements. The wind tunnel is turned on and the air speed is increased in steps of 2m/sec each. The generated power is measured as the product of the voltage and the current in the outside circuit. Next, the rear rotor is introduced to the generator shaft with a 12cm distance behind the front rotor. In order to mimic the slow motion of the real rotor, electric power was supplied to the generator with a controllable voltage from a stabilized power supply. Normally, if this rotating speed control method is not used, the rotor speed increases as the tunnel air speed increases. The voltage supplied to the generator is increased to maintain the same RPM of the rotor. The power supplied is equal to the power generated at this slow steady rotation and is taken as a measurement of the power output of the assembly. Results were compared to tests with only a single rotor model. The power produced from the two-rotor turbine was nearly double that of the single rotor.

Fig. 1. Testing of The Dual-Rotor Wind Turbine in the subsonic wind tunnel.

4.Computational and Numerical Results

Two identical rotors were simulated in a uniform free stream having a wind speed of 10 m/sec ,the CFD software uses virtual wind turbine with dimensions 1x5x1 m , step time =0.001 seconds , and frame frequency = 50 Hz ,Figs. 2(a)-2(e)] and [figs 3(a)-3(e)]. The two rotors were allowed to rotate as a result of the forces generated on each. After reaching a steady state, the flow pattern was recorded and streamlines drawn on a 'top view' of the assembly , fig 2(a)-fig2(e) vorticity cut plane , fig 3(a)-fig 3(e) voricity visualization field



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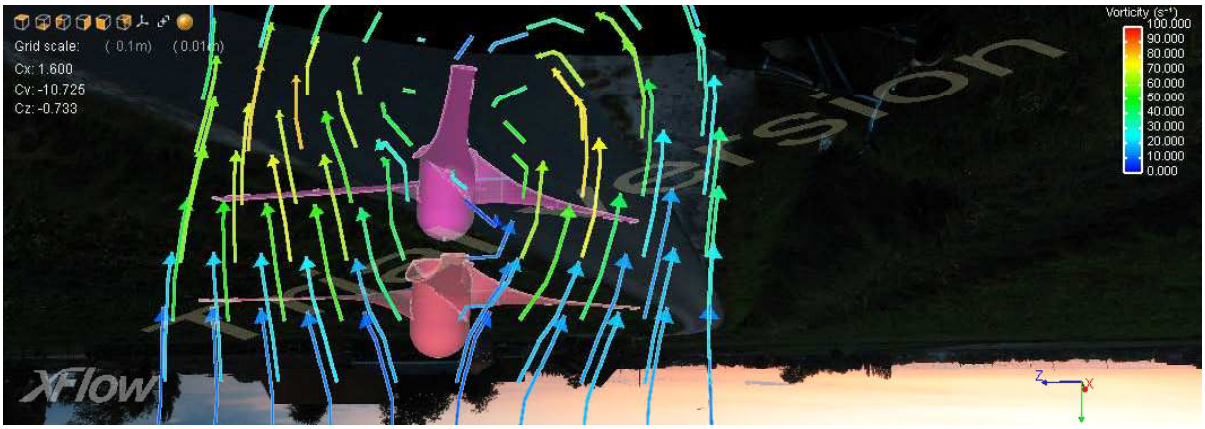
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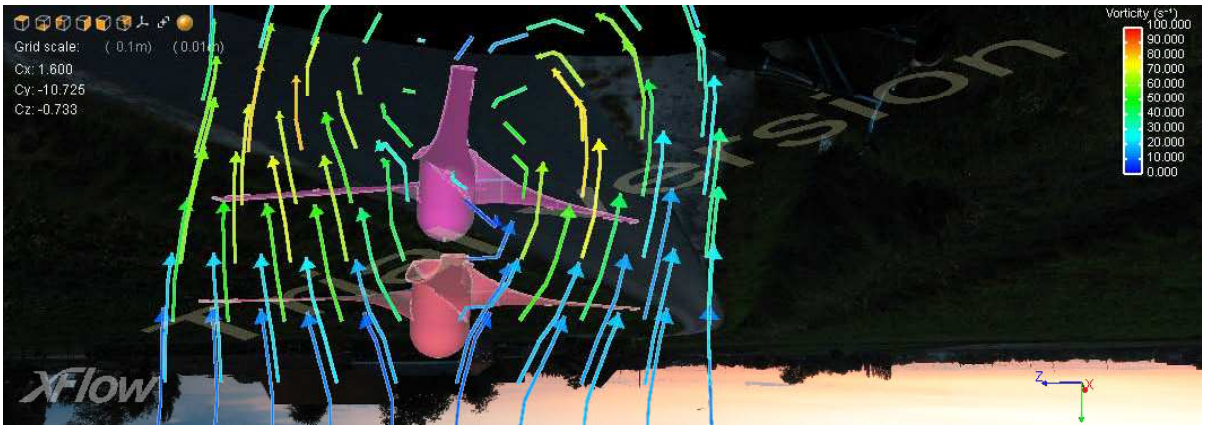
40.000
30.000
20.000
10.000
0.000
XFlow

(b)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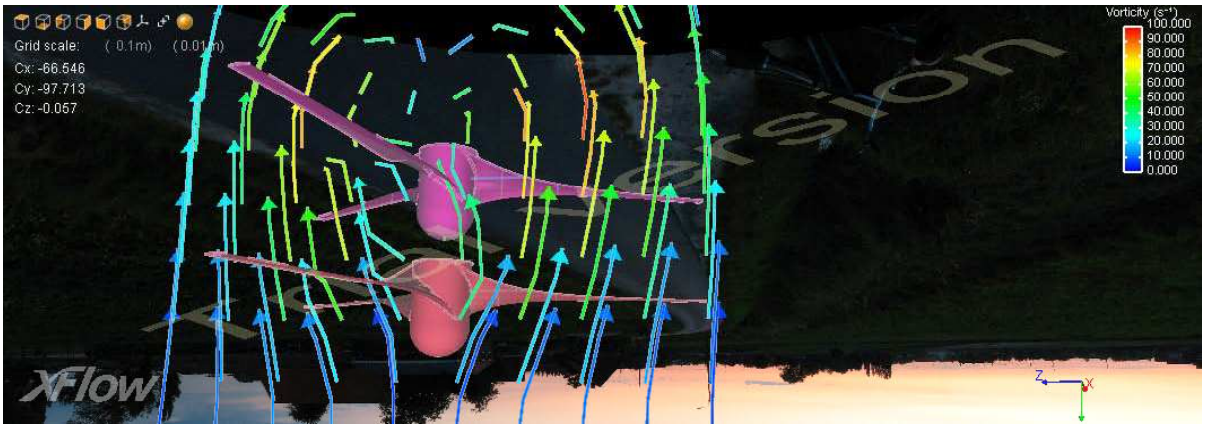
(c)



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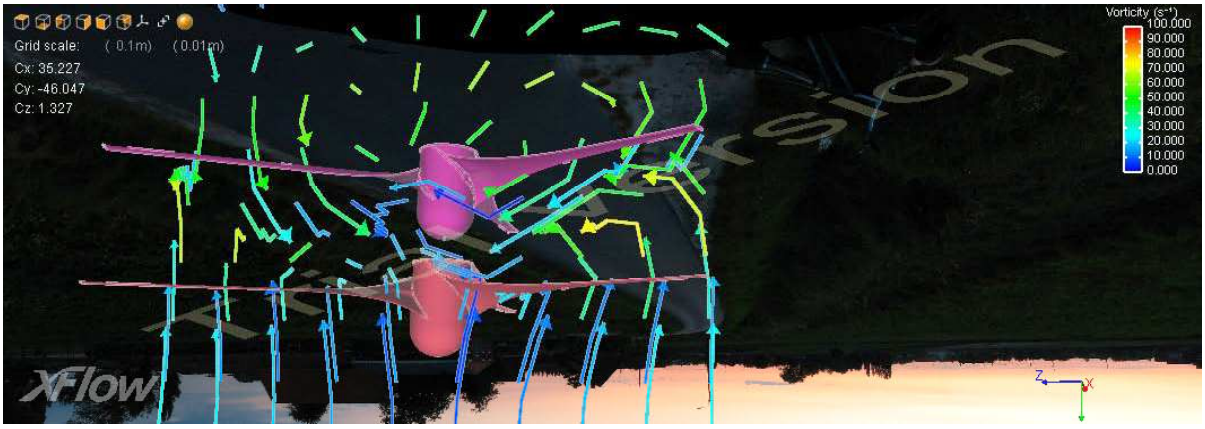
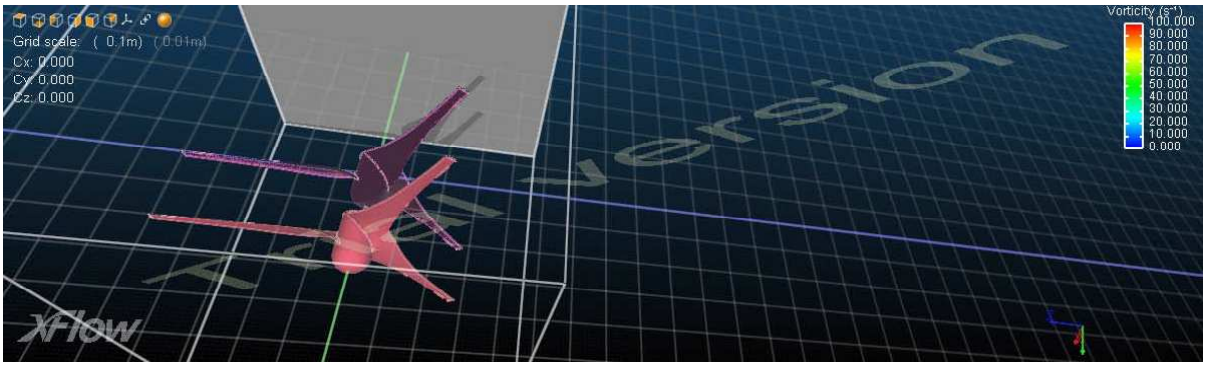


(e)

Fig.2. dual rotor wind turbine vorticity cut plane .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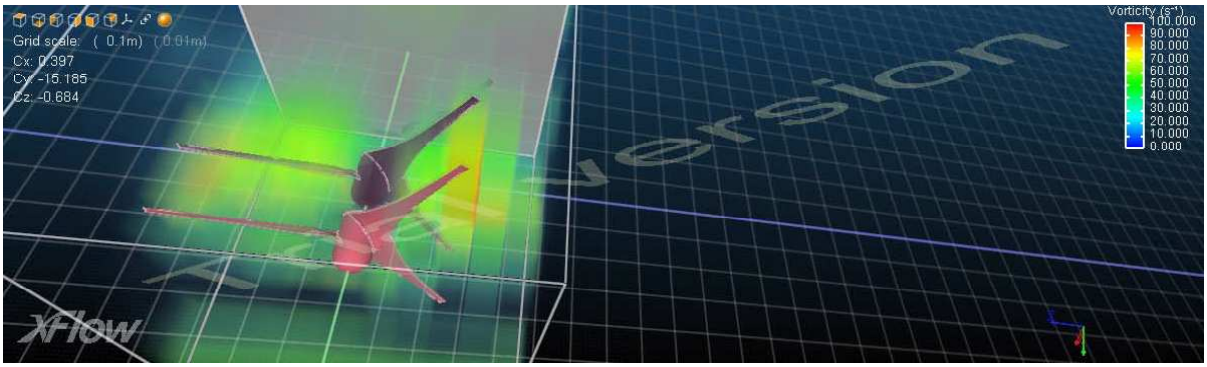
XFlow

(a)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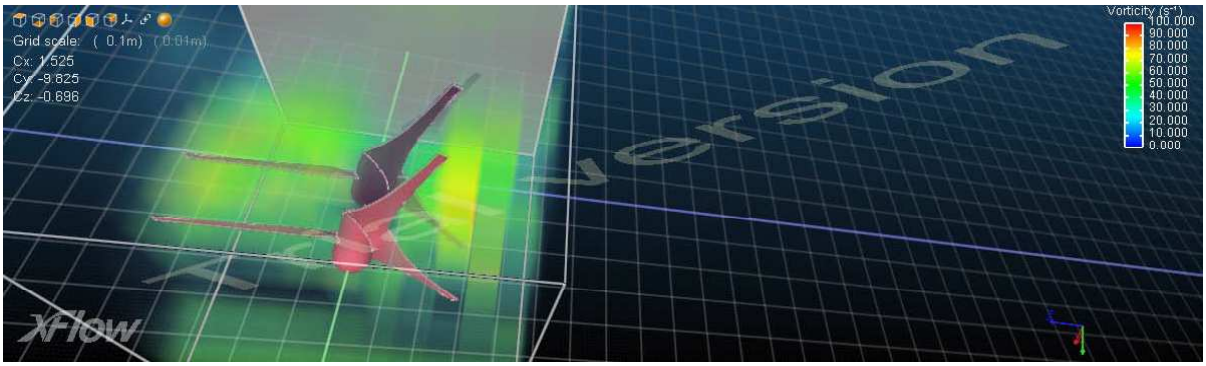
XFlow

(b)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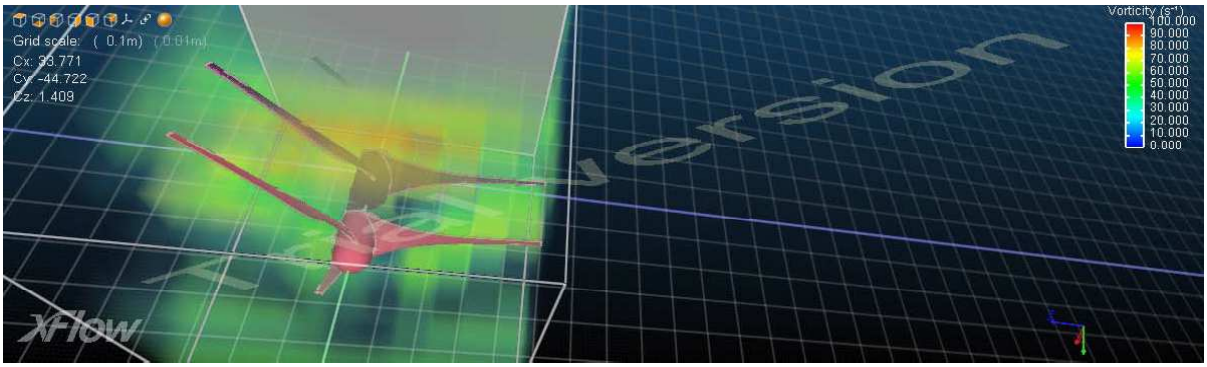
XFlow

(c)



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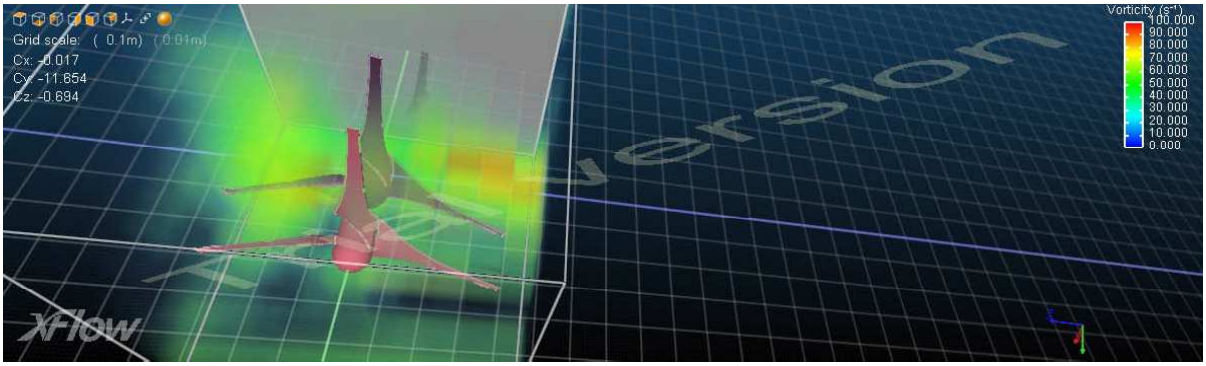

(e)

Fig 3 . vorticity visualization field of the dual rotor wind turbine

5.0 Results:

The results shown in figures 2.a – 2.e confirmed the that the wakes generated from the first rotor pass in between the rear rotor blades and does not interfere or hit the rear blades thus allowing full utilization of the free stream energy at the rear rotor location , the arrows indicates the direction of the vorticity . Consequently, the noise generated from this configuration is nearly doubled.

as shown in figures 3.a - 3.e the wake goes in-between the rotor blades and does not hit the blades directly ,the wake regions are after the second rotor , the region between the rotors have the lowest vorticity values , red color indicates high vorticity values .

6.0 Conclusions:

- The dual rotor wind turbine can be used to generate electricity with high power conversion efficiency.
- To maximize the extracted power from the wind turbine, the wake generated from first rotor should not interfere with the second rotor blades, but in between the rotor blades.
- The vorticity generated in the first rotor do not affect the second rotor.
- The dual rotor wind turbine can be used for low speed ranges, for high speed ranges the wake generated in first rotor will interfere with the second rotor blades, and then a counter productive effect will be generated.
- Since the dual rotor wind turbine can be used in low speeds, it will be a good solution for the regions with low wind speed ranges.
- The wind turbine blades should be aligned equally in the same orientation to allow the wake generated in the first rotor to go in between the second rotor blades, other configuration may permit the wake to go partially in between the rotor blades.

References

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