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A REVIEW STUDY: DISTINCT RECENT ADVANCEMENTS IN H-TYPE DARRIEUS WIND TURBINE TO IMPROVE AERODYNAMIC PERFORMANCE

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Abstract

Vertical axis wind turbines (VAWT) have been at center of focus for research in wind energy convertors lately. Over the recent years, several attempts have been made to improve the performance of these energy conversion machines; H-type Darrieus wind turbine particularly. The H-type turbine is relatively simple in design and works on lift forces, however these turbines are not self-starting. This paper reviews distinct advancements made over the past five years in H-type Darrieus rotors, the study initially focuses in detail on problems associated with them resulting in their poor aerodynamic efficiency, followed by enhancements made as distinct variants of H-type turbines to overcome some of these limitations along with their results and improvement over conventional rotor design. The J-shaped rotor out of all distinct turbines setups tackled more performance issues than any other turbine variants and showed adequate improvements in overall performance – with having better self-starting ability to aerodynamic efficiency, this review study provides a foundation for future work to be carried on H-type Darrieus wind turbines' performance limitation.

Keywords: Vertical axis wind turbines; H-type Darrieus; Trends in wind energy.

1. INTRODUCTION

Vertical axis wind turbines (VAWT) have enjoyed a fair share of development over past few years, this accelerated interest in these wind machines may be due to exhausting options for improvements in Horizontal axis wind turbines (HAWT); which already are operating closest to betz limit than any other wind turbines and are commercially being employed all around the world [1], whereas there have been few installations of large scale VAWTs for experimental purposes; such as Éole; World's first largest Darrieus VAWT capable of producing 230KW - developed by Hydro-Québec and NRC (National Research Council of Canada) provided in Fig. 1, which however is no longer operable, similarly several attempts have been made to use VAWTs on a large scale, especially by Sandia Laboratories to promote these wind turbines but the infamous VAWTs haven't been as acceptable as its counterpart.[2]

Fig. 1. Éole; World's first largest Darrieus VAWT [2]

The VAWTs however, have been accepted relatively widely, on a smaller scale due to their attractive aesthetics as well lower acoustic pollution [3]. Recent developments in small scale VAWTs have been particularly successful in China and European countries [4]. China's Changhua County's Fangyuan Township has recently become home to a modern small scale turbine wind farm in Fig. 2, consisting of 432 turbines, each having a rated power of 3KW, makings farm's installed capacity about 1.3MW. [5]

Fig. 2. Fangyuan Township small scale wind farm [3]

2. FACTORS LIMITING EFFICIENCY OF H - TYPE VAWT

This wide acceptance of small scale VAWT is due to elimination of various aerodynamic issues resulting in undesirable performance, the Darrieus wind turbine, particularly the H-type Darrieus turbine has been the most attended turbine of all types of VAWTs, this is due to their simpler design, easier construction and relatively lower costs. This sections discusses the aerodynamic issues which limits performance of H-type VAWTs [6]. The factors limiting the performance of VAWTs are:

2.1 H-type Darrieus wind turbine is basically a cross axis wind turbine. An important parameter that can provide tracking of their aerodynamic performance of these turbines is azimuthal angle, "the angle between turbine axis to the blade position". The Darrieus wind turbines are divided into four different regions; upwind, downwind, windward and leeward – based on azimuthal angle coverage illustrated in Fig. 3. The flow regime in a typical cross axis wind turbine is such that the upstream (U_∞) flow strikes 50% of the turbine (0 – 180°) directly and passes through to strike rest of turbine (180 – 360°), as shown in Fig. 4.

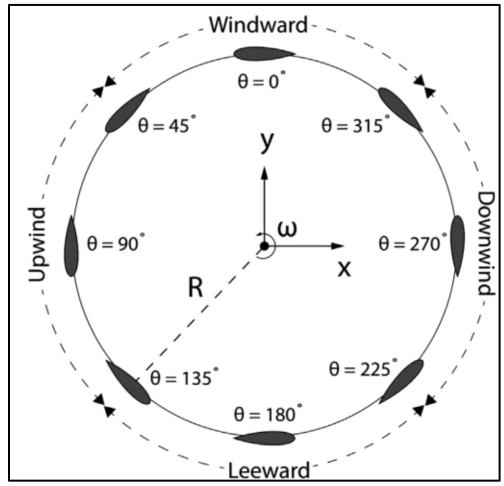

Fig. 3. Nomenclature of Darrieus VAWT [6]

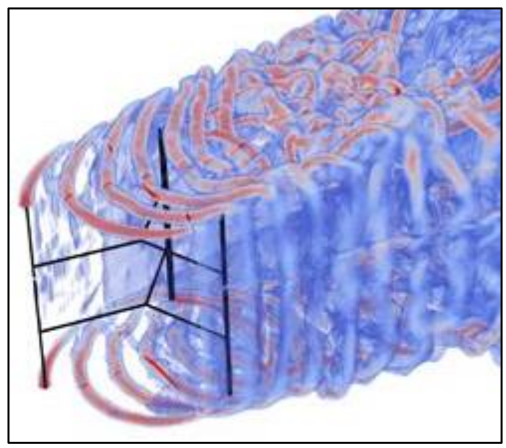

Fig. 4. Qblade Illustration of wind flow for VAWT [6]

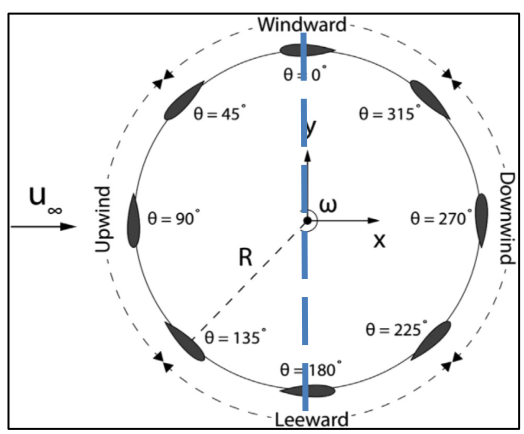

Fig. 5. Divided Upstream and Downstream section [6]

Hence, only 50% of the H-type wind turbine receives untapped power of wind stream (U∞) whereas rest of turbine receives turbulent, depleted wind stream - resulting in poor extraction of energy from available wind stream at downstream (shown in Fig. 5.) in comparison to a conventional horizontal axis wind turbine; whose entire blades receives the unobstructed wind power. [6]

2.2 Development of Negative Torque; all vertical axis wind turbines are prone to development of negative torque; when a VAWT is exposed to a wind stream the wind stream strikes initially the 50% of turbines portion and then the rest of 50% as the wind progresses through the turbine's cross section as explained in earlier sub-section. In fig. 6 it can be seen that the airfoil is moving in an wind ward direction from angle 315º to 45º the position of the airfoil is such that the it is moving against the wind stream, hence the oncoming upstream (U_∞) acts as a resistance against the moving blade in opposite direction (during the wind ward region) causing an induced negative torque, which reduces the overall positive torque development as a result lowers torque output in these turbines. [7, 8]

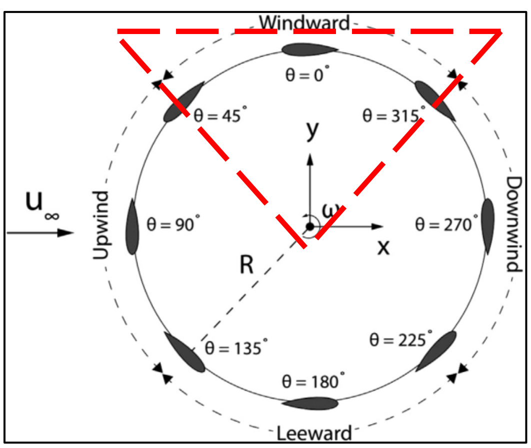

Fig. 6. Windward region in Darrieus turbine [6]

2.3 Irregular Exposure to Oncoming Wind; the Darrieus H-type turbines have a poor self-starting ability which is due to only half portion of the turbine is facing the upstream wind (U∞), and usually an irregular angle of attack of the wind impinging on blades at the front, while extremely undesirable angle of attacks on the blades at the back [9] – shown in Fig. 7, which causes irregular exposure for wind turbine to upstream wind. As a resultant the forces impinging on the turbine due to air speed are insufficient to cause turbine rotation, therefore these wind turbines are unable to self-start even at marginal wind speeds (4 - 5 ms^{-1}). [10, 11]

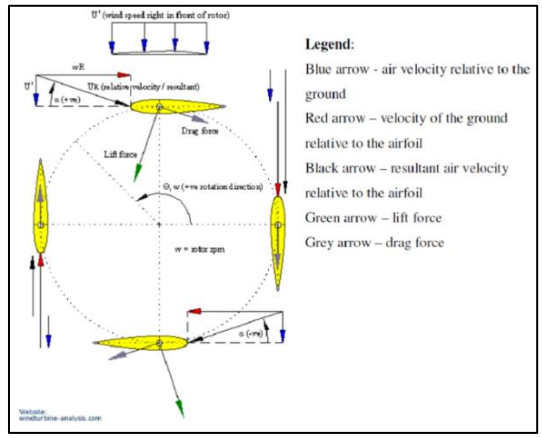

Fig. 7: Wind stream and blade orientation [10]

2.4 Inconsistent Angle of Attack; the H-type Darrieus wind turbines while rotating will generate lower power than HAWT because of unfavorable angle of attack, the angle of attack during the entire rotation changes which shifts from high stall angles to zero lift angles causing an imbalanced generation of rotation as well fatigue loads, and extreme stall conditions – shown in fig. 8- the stall condition causes vortex shedding resulting in inefficient aerodynamic power extraction. Whereas the irregular angle of attack during the operation of the turbine is provided in fig. 9; illustrating the vortex shedding due to change in relative change in angle of attack as the turbine rotates.[12]

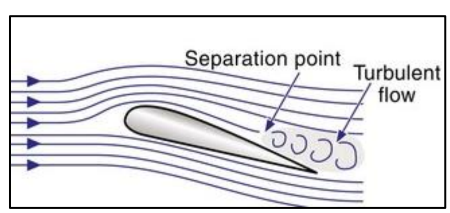

Fig. 8. Flow Separation around an airfoil [12]

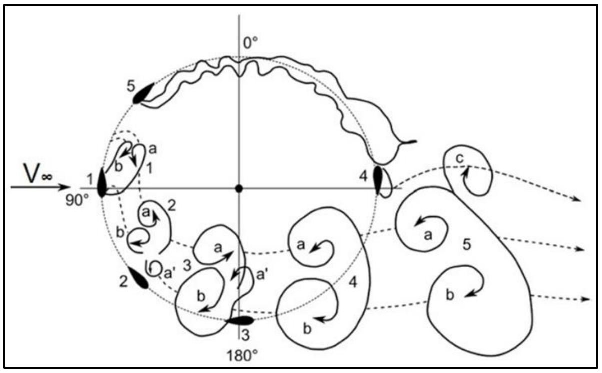

Fig. 9. Vortex shedding tracking by a single blade [12]

2.5 Inference – The factors limiting the aerodynamic performance can be assigned numbers or Alphabets in order to allow ease in determination which development in H-type wind turbine design tackled or mitigated the problems or factors to break the deficiency dead band. Table 1 shows all the limiting factors, their impacts and allotted alphabets.

Table 1 – Turbine Categorisation w.r.t Problems

Factor	Impact	Assigned Symbol
Cross Axis Machine	Turbine's downstream portion (50%) is unable to receives depleted upstream wind power	A
Negative Torque	Reduction in overall torque development and power	B
Irregular Exposure to wind	Poor Self-starting characteristic; insufficient starting torque	C
Varying angle of attack	Induction of vortex shedding – causing poor aerodynamic flow	D

3. DISTINCY EVOLUTIONS OF H-TYPE DARRIEUS WIND TURBINE

The H-type Darrieus wind turbine has undergone drastic changes over the past few years, conceptual basis, however only few concepts have been further developed by researchers and made into functioning turbines, the turbine's included in this paper are distinct advancements that tackled one or more factors limiting the aerodynamic constraints in improving H-type performance, shown in Fig. 10.

Fig. 10: Distinct Variants of H-Type Turbine

3.1 Trailing Edge Tubercle Bladed Darrieus Turbine is inspired by nature, the humpback whale – shown in Fig. 11, is an aquatic animal known for its agile maneuvers, and the credit for agility goes to the whale's fins provided in Fig 12. The fins consists of tubercles; which allows generation of irregular vortices that interferes with regularly generated vortices, reducing the overall turbulence behind the fins, created otherwise by regularly generated vortices; resulting in reduced flow separation. This adaptation was carried in a wind turbine blade to improve its efficiency, the work carried out by Lin et al. on vertical axis wind turbine was CFD based, they investigated the effect of different sizes of tubercles on the turbine's performance and observed an approximately 16% increment in the coefficient of performance, the tubercle blade Darrieus H-type VAWT is shown in Fig 13. [13-15]

Fig. 11. Humpback Whale [13]

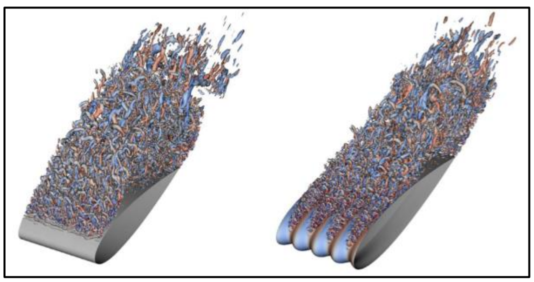

Fig. 12. Regular foil section against Tubercle based [13]

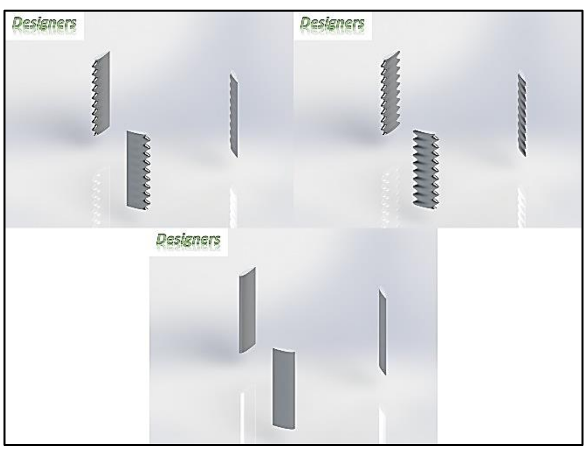

Fig. 13. Tubercle trailing edge VAWT [13]

3.2 Cross Axis Wind Turbine (CAWT) was developed by W.T. Chong et al. The CAWT is a turbine made by combining a horizontal axis wind turbine with a Vertical axis wind turbine, the design of CAWT is illustrated in Fig. 14, and horizontal turbine replaced the conventional mainlinks – connecting arms in a VAWT. The experimental results have shown that the CAWT produced greater power and had an increment in COP by two fifth. The superiority in performance of CAWT is due to utilization of wind speeds that are outside the turbine's span, the wind stream moving below the turbine may be directed upward for the utilization by Horizontal blades. [16] The developed prototype is presented in Fig. 15.

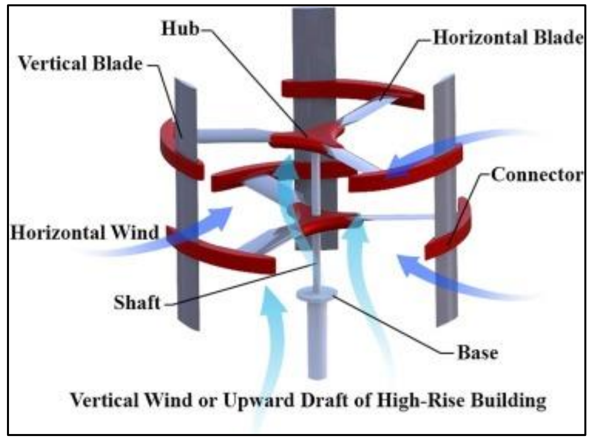

Fig. 14. CAWT CAD design [16]

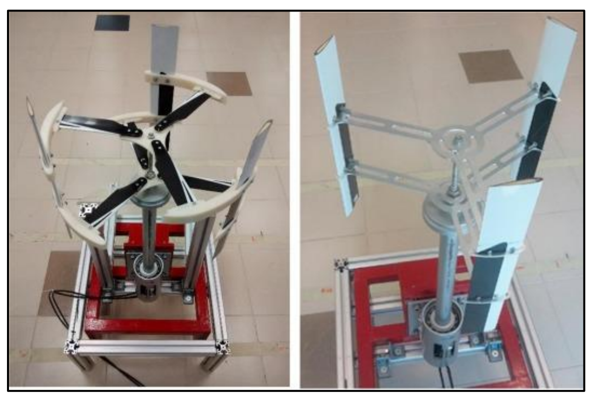

Fig. 15. Experimental prototype CAWT and VAWT [16]

3.3 Combined Savonius Darrieus Wind Turbine has shared the most limelight in being considered as efficient type of VAWTs, they have been research upon the most and have shown improvements over the turbine, In 2014 – Taiwan mass produced a version of these turbines and have sold several of them, these are also the turbine that have recently been used in China's first borrowed aquatic farming land [5], the turbine consists of a Savonius rotor that acts as an auxiliary rotor to a Darrieus rotor shown in fig. 16 [17, 18]. The Savonius rotor provides initial torque to the turbine, improving Darrieus rotation and self-starting characteristics [19], experimental work shows that the combined wind turbine can be arranged in different configurations, additionally the COP improvement at lower wind speeds is 1.5 times, however if rotated at a much faster rate – the attached Savonius wind turbine will act as a drag body and may potentially reduce turbine's efficiency, even lower than conventional wind turbine [20].

Fig. 16. Combined Savonius Darrieus wind turbine [20]

3.4 Auxiliary bladed Darrieus wind turbine (VAWTAB) was tested by M. Scungio in order to assess its performance, the experimental results showed that despite conventional VAWT having peak COP higher than peak COP of VAWTAB, the VAWTAB had better overall performance and significant improved self-starting abilities, the conventional Darrieus started at 10 m/s whereas VAWTAB was able to start 6.5 m/s – translating that the turbine will generate more power, additionally the CFD revealed that the turbine has auxiliary blade reduces the flow separation by reattaching the separated layer from the auxiliary blade to the actual blade [21, 22]. The auxiliary blade illustrated in fig. 17, also helps reduce the negative torque by aiding in positive angle of attack. [23]

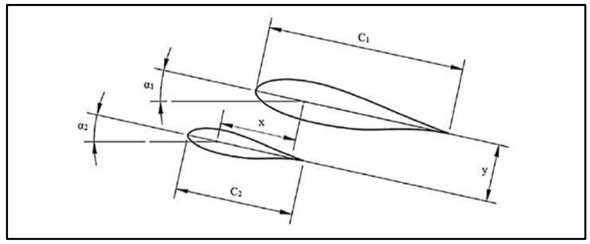

Fig. 17. Auxiliary blade (lower blade) for VAWT [21]

3.5 J-shaped Darrieus Wind Turbine; the J-shaped Darrieus wind turbine is the least complicated advanced version of H-type Darrieus wind turbine, the turbine was developed and worked on by M. Zamani et al. [24], the J-shaped blade was formed by removing some portion of pressure side of a regular airfoil shown in Fig. 18.

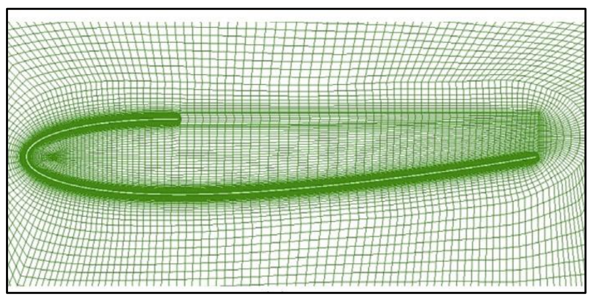

Fig. 18: J-shaped airfoil [7]

The study was based on CFD using Open Foam, and assessed several different percentages of pressure side removal to determine the optimum ratio, the J-shape blade was then compared with conventional blade and it was concluded that the J-shaped wind turbine had better performance, it had better torque development, adept self-starting abilities, less fluctuations and higher coefficient of performance, the J-shaped blade allows the simultaneous utilization of lift and drag forces, while the J-shaped bucket like blade transported the separated layers of air from the blades from the upstream to downstream instead of letting them pass through the cross section and cause irregularity in the flow of air stream [7, 25, 26]. The J-shaped variant of H-type Darrieus and conventional H-type turbine are provided in Fig 19 – 20, respectively.

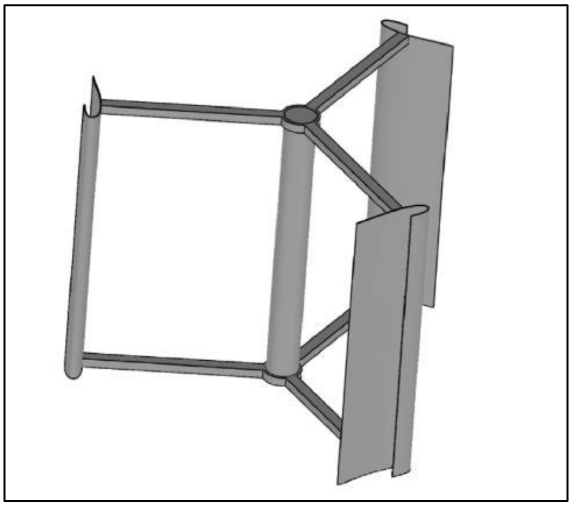

Fig. 19: J-shaped VAWT [25]

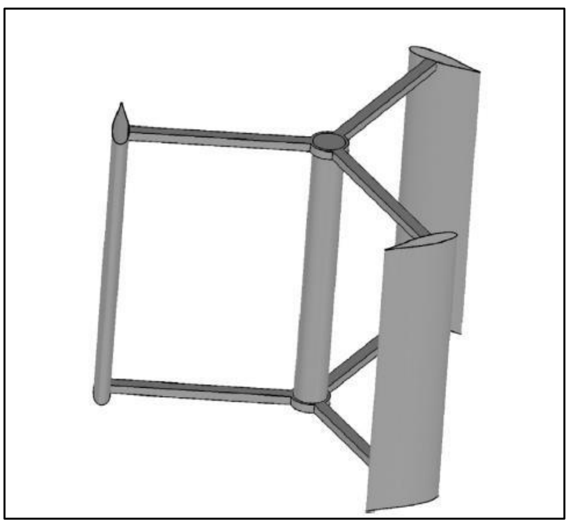

Fig. 20. Conventional H-Type VAWT [25]

4. CONCLUSIONS

The Recent variants of H-type Darrieus can be showed promising results in improving the conventional H-type VAWT, the variants were able to provide better result by overcoming the limiting factors, which were classified as A,B,C and D earlier in this study, table 2 shows summarized table of how many issues each variant tackled.

Table 2: Trends cateorisation w.r.t. problem solved

VAWT Variant	Impact	Tackled Issues
Trailing Edge Tubercle VAWT	1. Reduction in vortices generation	D
Cross Axis VAWT	1. Self-starting Ability 2. Higher Torque	C
Combined Savonius Darrieus VAWT	1. Self-starting Ability 2. Higher Torque	C
Auxiliary bladed VAWT	1. Self-starting Ability 2. Reduced Negative Torque development 3. Reduction in vortices generation	B, C, D
J-shape VAWT	1. Self-starting Ability 2. Reduced Negative Torque development 3. Transported Separated flows from upstream to downstream outside the loop rather than from cross-section 4. Reduction in vortices generation	A, B, C, D

The J-shape Darrieus, H-type Variant out of all distinct advancements was able to tackle the identified aerodynamic issues in the literature and showed significant improvement in performance characteristics, hence should be studied experimentally for better performance analysis as well annual energy production capacity and LCOE (levelized cost of energy).

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