

Pitch Control Systems in Vertical Axis Wind Turbines: A Review

Mukesh Kumar Rathore ^{1*}, Meena Agrawal ², Prashant Baredar ³

^{1*, 2, 3} Energy Centre, Maulana Azad National Institute of Technology, Bhopal 462003, M.P., India

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Mukesh Kumar Rathore (Corresponding Author)

Energy Centre, MANIT Bhopal, M.P.

India. 462003

(M): +91- 7987077709

Email: mrathore96@gmail.com

Dr. Meena Agrawal (Co-author)

Energy Centre, MANIT Bhopal, M.P.

India. 462003

(M): 9425602012

Email: oshomeena@gmail.com

Prashant Baredar (Co-author)

Energy Centre, MANIT Bhopal, M.P.

India. 462003

(M): 9406511666

Email: prashant.baredar@gmail.com

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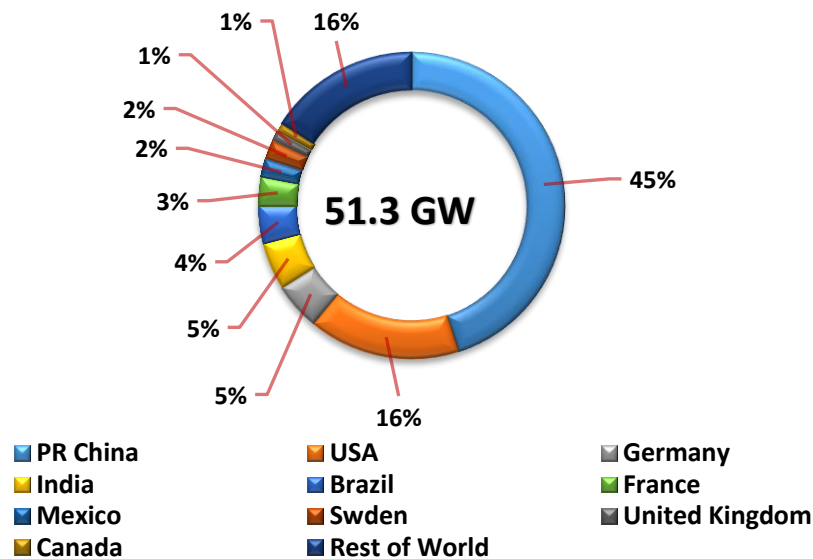
Abstract: Due to rising interest in wind energy harvesting offshore as well as in the urban environment, vertical axis wind turbines (VAWTs) have recently received renewed interest. Their omni-directional ability makes them a very fascinating choice for use with the frequently varying wind directions. The main concern in this turbine is self-starting at low wind speed, turbulence and stability issues at very high wind speed. Under such conditions, pitch angle is a potential parameter to enhance the performance of VAWTs. Thus pitch control systems becomes essential parts of VAWTs. The current work presents a detail over view of various pitch control configurations in VAWT. Various research work carried out in this field has been studied critically and the stream field around the blade, features of various pitch control systems, their merits and demerits have also been discussed.

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1 **1. Introduction**

2 Owing to the ever-rising interest in the versatile electrical power, with reducing and polluting fossil fuel
3 resources, the new and sustainable sources of energy are under genuine thought [1]. Wind energy creates
4 no pollution and generates no greenhouse gases while processes such as carbon dioxide and methane [2, 3].

5 In 2016 and 2017, the new wind energy capacity extended up to 54.6 GW and 52.6 GW respectively [4,5]
6 2018 was a good year for the global wind industry with 51.3 GW of new wind energy installed, a minor
7 fall of 4.0 percent w.r.t. 2017, [6] The whole capacity of all wind turbines installed globally by the end of
8 2018 touched 597 GW. Throughout the last few years, wind power schemes were established rapidly due
9 to the enthusiastically appeal of renewable energy. By the end of 2019, the wind power capacity is
10 predictable to reach 666.1 MW [7].



11 Fig. 1. Global wind industry with 51.3 GW of new wind energy installed in the year 2018 [6].
12 The worldwide vertical axis wind turbine market to rise at a Compound annual growth rate (CAGR) of
13 14.98% during the period 2018-2022 [8].

15 Wind turbines have been historically known to be mounted in open rural areas but nowadays, there has
16 been expanding attention for the VAWTs in urban zones [9]. HAWTs have for quite some time been used
17 in huge-scale farms of wind, as well as more productive than VAWTs in the stable wind but in the small
18 scale, HAWTs take additionally existed progressively actualized at manufactured situations. Although,
19 recent several analyses keep demonstrated that in urban zones VAWTs achieve better whenever relating
20 over HAWTs. The HAWT farms are normally found far from populated regions and depend on the

horizontal non-turbulent wind profiles [10]. Moreover, in urban zones the wind is violent and uneven with quick varies in direction and speed [11]. In these conditions, the VAWT has a few favourable circumstances over HAWT [12]. The variability of the wind source considering, that the wind turbine will be over-burden and crash down the electric structure and the mechanical structure of when too high wind speed blows and the turbine is still functioning at a [13]. In small to medium scale wind turbines in the urban condition the VAWT is feasible with its utilization [14]. Recently have VAWTs gotten expanded exploratory, numerical, and systematic consideration, a pattern that is inferable from their capacity to accomplish useful power generation yet with less noise [15]. The Savonius rotor is a vertical axis wind turbine that works under a differential drag between its containers. The Savonius rotor is promising answer for low wind speed conditions, however it's efficiency is low [16]. The basic physics behind the power generation of VAWTs is substantially more difficult as compare with HAWTs [17-23].

Not at all like both HAWTs, VAWTs are at present intended to work at constant rotational speed for the most part because of effortlessness and expenses [24-26].

Utilizing the VAWT technology for huge power generation activities was mostly unnoticed because of their lower efficiencies w.r.t. the technology of HAWT. However, variable-pitch Darrieus VAWT mechanism design, also called giro mill having about 0.5 coefficient of power (C_P) [27-29] as compare to the HAWT.

Moreover, while VAWTs have lower aerodynamic efficiency, there is some proof that VAWTs can be situated nearer together in wind farms giving a higher power concentration because of lower wake interference [30]. Nevertheless, the aerodynamic performance of VAWTs is currently poorer than HAWTs [31-34].

Vertical axis wind turbines (VAWTs) have reappeared as promising energy conversion appliances due to a multiplicity of spic and span strategies that can advance as far as possible [35-40]. Also, the effect of different geometrical parameters and operational parameters on the aerodynamic performance of VAWTs should be extensively portrayed. The geometrical parameters incorporate number of blades [41-43],

solidity [44–46], airfoil shape [47–48], blade pitch angle [49] and turbine shaft [50] Mertens et al. recommended such a conditions of twisted flow, the airfoils depend just on the symmetrical segment of the approaching wind speed by lift and drag forces generated, though the parallel part adds to the zero impact on the outside of the airfoils. This is known as the cross-flow principle [51, 52], either wind speed represents the cooperating with the vertical rotor blades slanted flow to turn into a factor of both the skew angle of and the induction factor stream tube. [53, 54] In certain examinations, for the VAWT the cambered airfoil is ideal because the turbine's efficiency in energy extraction might be impeding of virtual camber impact [55, 56]. In some current examinations, in a violent atmosphere, the type of vertical wind rotors can work effectively more [57–61].

The vertical axis wind turbine blade is expected to upgrade by dynamic pitch structure to improve the whole rotor implementation were made by [62–64] Comparable perceptions. Dynamic pitching has as of late gotten enthusiasm as a promising answer for execution enhancement [65-67]. For this situation, the pitch angle of every blade changes with the azimuthal position. The ideal pitch angle appropriation over a transformation can be resolved from high-fidelity CFD simulation or explores and will by and large be unique in relation to the traditional cyclic pitching previously researched for VAWTs [68, 69].

What type of impact of pitch angle on power execution and aerodynamic features of a VAWTs was considered by Rezaeiha et al.[49, 70] In request to get the aerodynamic force for the basic plan of the blade, the Double Multiple Stream Tube (DMS) code has been included [71, 72].

A standout among the most essential control mechanism of a wind turbine is the pitch control, which directs control over the rated wind speed and protects blades during very high wind speed. [73]. If torque ripple of comparable virtual amplitude as simulated in Ref. [74] would be available on the shaft, it could influence the rotational speed of the generator rotor. [74]. If the rotation of the blade pitching is appropriately set in front of the focal point of force, at that point blade pitch drive will produce power as opposed to expending it. This produced power somewhat makes up for the expended power, with the goal that the mean power expected to impel the blade during a turbine's upheaval is least [75]. As an outcome, the pitching guideline, which can restrain the power production and relieve turbine blades burdens actuated to the wind turbine

72 airfoil is critical by the Angle of Attack (AoA) change respectively, [76]. To improve VAWT execution a
73 variable pitch mechanism is connected Through the variation of the angle of attack (α). A variable pitch
74 angle control mechanism can be both of two principal classifications: passive or active [77]. Be that as it
75 may, the VAWT execution to crumble at high TSRs causes huge pitch amplitude. It will prompt poor
76 performance at low TSRs Then again, at high TSRs while a small pitch abundance is adequate to create
77 great performance [78, 79] More VAWTs with variable pitch were tried small wind tunnels, either with
78 passive mechanism [1, 9, 80, 81].

79 Along these lines, poor self-starting limit and low productivity are real advancement problems for straight-
80 bladed VAWTs [82-84]. Subsequently, four classifications that measure changes were carried taken by
81 engineers and researchers, which fall into: (i) Blade pitch control, (ii) Guide vane, (iii) Combined rotor, (iv)
82 Special aerofoils [9]

83 In addition, the improvement of the starting capacity the most effective way is the blade pitch control
84 methods were observed. For a self-acting pitch control linkage system approach scheme is utilized to assist
85 a multi-body and various pitch control scheme was discussed. With regards to the VAWT, during the
86 procedure of rotation of the blade, the state of getting impacts is superior to that of the HAWT, because the
87 directions of the inertial drive and gravity keep stable ever.

88 Analysis of the aerodynamic performance of a vertical axis wind turbine with dissimilar sequence airfoil
89 profiles. different types of airfoils and different tip speed ratios were calculated to overpower coefficients:
90 i) different maximum thicknesses but same maximum thickness position with symmetrical airfoils; ii)
91 different maximum thickness positions but same maximum thickness with symmetrical airfoils, but; iii)
92 different maximum cambers but same maximum camber position, same maximum thickness position, non-
93 symmetrical airfoils with same maximum thickness; iv) different maximum camber positions but same
94 maximum camber, same maximum thickness position, non-symmetrical airfoils with same maximum
95 thickness, The power coefficient of VAWT indicated inclination that discovered at first increment and after
96 that lessening for symmetrical airfoils with same greatest thickness and same most extreme thickness

position with tip speed ratio increases. [85] For VAWT, wind tunnel analysis is likewise a positive strategy for survey the aerodynamic observes on the blade and around the rotor [86-88]. Performed wind tunnel tests to realize the impact of solidity at the various number of blades on aerodynamic forces around a straight-bladed VAWT. It was decided that power coefficient diminishes when solidity raises, while torque coefficients raise [89-92].

A new control method an internal model controller (IMC) and an individual pitch controller (IPC) based on the use of two supplementary controllers was proposed to reduce the vibrations of the tower and wind turbine overload, thus extending lifetime and performance of the turbine improves. To recognize the frequency of vibration on internal control model was used and the signal of the vibration mitigate a new control system established, in actual turbines cannot be determined accurately as the frequency of the vibration [93].

Table 1 The VAWT comparison with HAWT. [94]

	(VAWT)	(HAWT)
<i>Ideal efficiency</i>	More than 70%	50–60%
<i>Noise production</i>	Quite Less	Relatively high
<i>Self-starting capacity</i>	No	Yes
<i>Whole construction</i>	Easy	Difficult
<i>Blade's action space</i>	Small	Large
<i>Obstacle for birds</i>	Fewer	More
<i>Ground height</i>	Lesser	Big
<i>location of generator</i>	Ground level	Top site
<i>Direction of wind</i>	Multisite	Single site
<i>Yaw control mechanism</i>	No	Yes
<i>Tower sway</i>	Small	Large

108
109

2. Summary of the pitch control mechanism of VAWT

VAWT has been changing in blade pitch angle to produce maximum power. That kind of active or passive pitch control mechanism possible. Changing pitch too fluctuations the volume of torque and the angle of attack of the relative wind. Variable pitch gives more control choices than stalls control. Then again the hub is increasingly complexity because pitch variation behaviours must be integrated. In addition, some type of pitch actuation mechanism must also be involved. In specific wind turbines, just the external piece of the blade might be pitched [95] this is known as partial span pitch control. An outline of various techniques utilized on behalf of blade pitching scheme are as follows:

118 • Passive pitch control

119 • Active pitch control

120 A Passive pitch control mechanism utilizes aerodynamic forces to activate self-starting components and

121 workings via making pitching instant around blade axis turn such technique remains completely in the

122 separate streamlined capacity adjust. On individual blade, behavior depends on the streamlined load adjust

123 at a detailing of the pitch angle. To execute such technique preparation, so that this is hard to arrange an

124 ideal component working scope of the VAWT. Specific wind situations the controlling mechanism

125 exceptionally well performed. The VAWT industrially actualized not yet at this time however, found rather

126 a theoretical scheme. The passive pitch control mechanism is another mechanism that utilizes load-balanced

127 out or loads the spiral settled blade. A centrifugal force generated in which a mass go about as during

128 rotation. The computational fluid dynamics (CFD) simulations using a promising way to inspect the

129 complex phenomena that are present in an analysis of a VAWT with the pitch control mechanism [73].

130 An edge begins at a higher approach at lower speeds to delivering torque. When the rotational speed

131 expands at the point, the load outwards is constrained, and to a decreased angle of attack, the blade is moved.

132 The aggregate pitch control mechanism is liable in the individual blade pitch control technique, these issues

133 of huge intricacy and vibration of plan parameters [96]. The individual pitch control mechanism for VAWT

134 demonstrated streamlined execution of expansion in execution via 60%, for instance, contrasted and

135 without pitch control usually VAWT.

136 On the systems a detailed forecast perspective based model other side Model Predictive Control (MPC)

137 control algorithm employed above to expect future production. At respectively compute operational the

138 prediction of the control action over the horizon of sample an optimization difficulty is resolved. However,

139 allowing for system controls is to compute the optimal control action with the advantage of using MPC.

140 The procedure of wind energy conversion systems discrete-time MPC according to controllers have been

141 suggested to control [97].

Moreover of three mechanisms in the pitch angle control strategy. The operational point of the pitch first mechanism μ_o the average wind speed at the hub height match up to angle that be determined. In the IPC action, the second mechanism μ_{ipc} is to reduce the flap wise moment on individual blades. As in Ref. [98] in this action, the individual pitch control (IPC) action by using a conventional proportional plus integral (PI) controller.

The collective pitch control (CPC) action μ_{cpc} is the third mechanism is to adjust the generator speed and power to be at their rated values is the main objective. Explicit continuous-time model predictive control (ECMPC) is the design of a tube-based for CPC. U_p is the total pitch angle control action:

$$U_p = u_o + u_{ipc} + u_{cpc} \quad \dots\dots\dots(1)$$

Where, the pitch angle U_p in (1) features allowable scale level from 0 rad to 1.57 rad through of 0.139 rad/sec maximum rate of change [99] The CPC action input limits can be leveled from (1) as:

$$-u_{ipc} - u_o + u^{\min} \leq u_{cpc} \quad \dots\dots\dots(2)$$

$$-u_{ipc} - u_o + u^{\max} \geq u_{cpc} \quad \dots\dots\dots(3)$$

$$-\Delta u_{ipc} - \Delta u_o + \alpha^{\min} \leq \Delta u_{cpc} \quad \dots\dots\dots(4)$$

$$-\Delta u_{ipc} - \Delta u_o + \alpha^{\max} \geq \Delta u_{cpc} \quad \dots\dots\dots(5)$$

u^{\min} and u^{\max} are the minimum and maximum values of the pitch angle, respectively. α^{\min} and α^{\max} are the minimum and maximum pitch angle rates of variation, respectively. Hence, the CPC action u_{cpc} can be obtained by solving an optimization problem subject to the constraints in equation (2)-(5).

The operating TSR (λ) is the main factor related to VAWT blades and wind speed is the main reason for the choice of the TSR, this can be written as [100].

$$\lambda = \frac{\omega_r R}{\mu_\infty} \quad \dots\dots\dots(6)$$

Where ω_r is the rotor angular velocity, R is the rotor radius and μ_∞ is the wind speed [97].

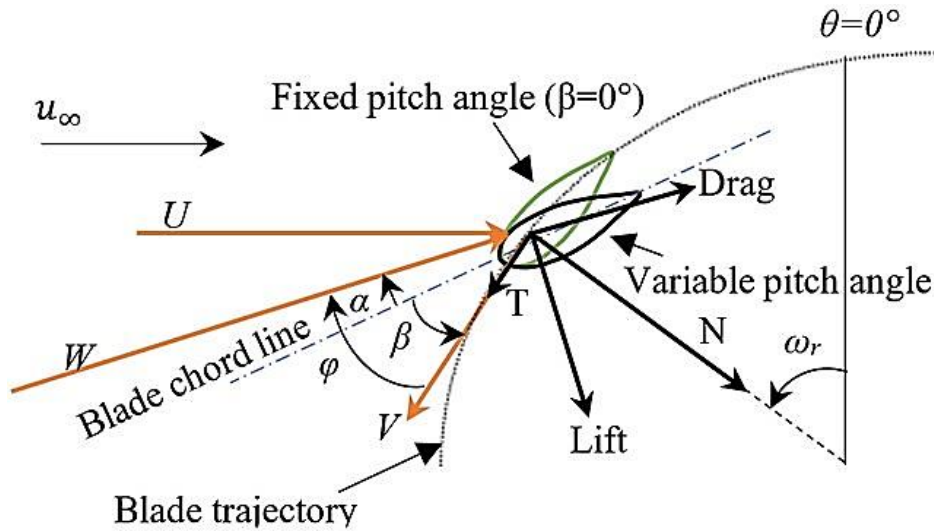


Fig.2 Velocities and Forces action on the blade [101]

The forces acting on each blade is determination can be predicted based on actual VAWT performance. The force and velocity vectors action on the blade of the Darrieus wind turbine shows in Fig. 2. The resultant velocity vector (\vec{W}) is the relative velocity that occurs by the induced velocity (U) and blade velocity (V) vectors. The velocity (\vec{V}) is the tangential velocity vector of the wind turbine rotor. The angle between the direction of the resultant velocity and the blade chord line is typically known as angle of attack (α).

The blade pitch angle

$$\beta = \alpha - \varphi \quad \dots\dots\dots(7)$$

Where φ is representing the angle between the vector direction of \vec{V} and \vec{W} . The function of the azimuth angle (θ) is both the angle of attack (α) and the relative wind speed (W) that fluctuate during each cycle. [102]

For a VAWT with a fixed pitch angle ($\beta = 0^\circ$) show the angle of attack α can be written as [103] :

$$\alpha = \tan^{-1} \left(\frac{\cos \theta}{\sin \theta + \lambda} \right) \quad \dots\dots\dots(8)$$

The wind turbine pitch control mechanism can change the frequency of rotor blade in a wind power control framework in view of continuous wind speed with the area of modifying pitch control, accomplishing greater usage effectiveness of the power of the wind and provide protection to the rotor blade. Some kind of when the wind speed is lower than the rated speed, the blade angle remains close to the angle 0° the most striking force of the point, which is with a consistent pitch like that of a generator, creating a wind power that wind speed alongside progressions. Another side when wind speed is higher than the rated wind speed,

the pitch angle control configuration is modified the blade rate so that the wind turbine generator is permitted extent power to the inside.

3. Various Experimental system with Pitch Control Mechanism

Elkhoury et al. assessed A 3-D review of the variable-pitch angle mechanism of the wind turbine is portrayed shows in Fig. 1. The diameter of 0.8 m and a height i.e. blade span of 0.8m of the turbine. The three straight blades VAWT each was associated by three fundamental roundabout bars with a diameter of 0.02 m each with the inside of the rotors. With the use of a four-bar linkage system is changing the pitch angle of three straight blade rotor.

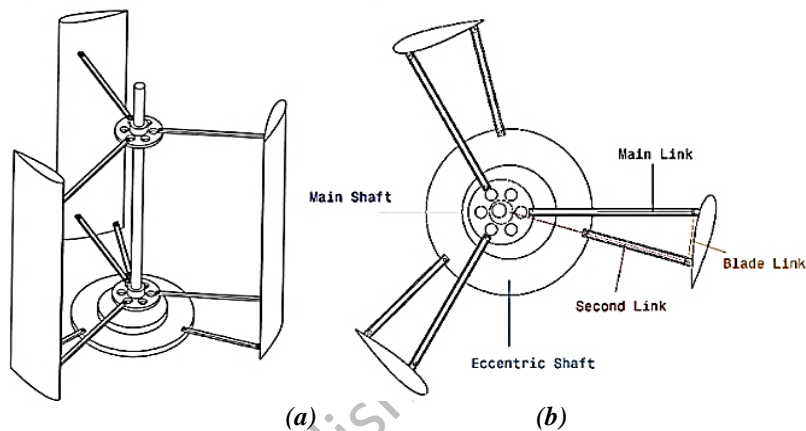


Fig.3: An overview of the wind turbine modeled
(a) Front view (b) Top view of the rotor [9]

This mechanism has an unconventional rotational focus which is not quite the same as the standard point of the rotating turbine as appeared in Fig. 3. In such manner, this system can an unformed mesh was picked and that id suited for small applications with unpredictable geometry. The mesh technique was prepared finer in this area given the fact that persuasive components of the VAWT were being drawn nearer.

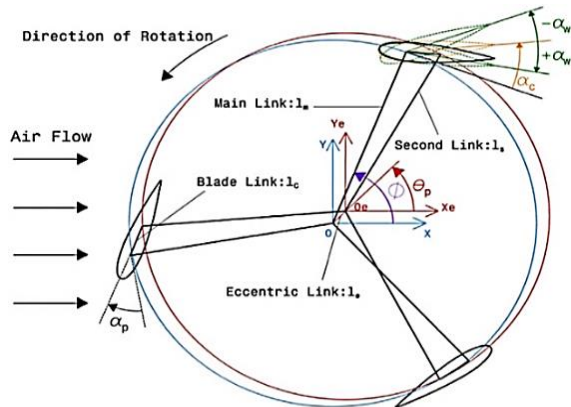


Fig. 4: Schematic sketch of the variable pitch angle system [9]

The equation of the pitch angle in each quadrant governing the motion can be written as

$$\alpha_p = \pi/2 - (\beta + \gamma) \text{ for } 0 < \varphi < \pi, \text{ and } \alpha_p = \pi/2 - (-\beta + \gamma) \text{ for } \pi < \varphi < 2\pi,$$

Where

α_p = Blade pitch angle

l_c = Blade link, α_c = blade offset pitch angle, α_w = the blade pitch angle amplitude

l_e = The eccentric link, l_m = the main link, l_s = Second-link, \varnothing = the blade azimuth angle

θ_p = The angle between the wind direction and the eccentric-link

d = Turbine diameter, h = Blade Span

$$\beta = \cos^{-1} \frac{d^2 + l_m^2 - l_e^2}{2dl_m}, \quad \gamma = \cos^{-1} \frac{d^2 + l_c^2 - l_s^2}{2dl_c} \quad \dots\dots\dots (9).$$

$$\text{For } \alpha_p = \pi/2 - \varepsilon \text{ for } \varphi = 0 \quad \text{for } \alpha_p = \pi/2 - \delta \text{ for } \varphi = \pi$$

$$\text{Where, } \varepsilon = \cos^{-1} \left(\frac{l_c^2 + (l_m - l_e)^2 - l_s^2}{2l_c(l_m - l_e)} \right), \quad \dots\dots\dots (10)$$

$$\delta = \cos^{-1} \left(\frac{l_c^2 + (l_m + l_e)^2 - l_s^2}{2l_c(l_m + l_e)} \right) \quad \dots\dots\dots (11)$$

The bars and shaft were treated with fine face sizing and swelling layers to precisely catch flow variations within the limit layer. Besides, a no-slip limit condition was set for all bars and shafts [9].

- Lixun et al. carried out the variable-pitch instrument comprises of four belt wheels, one servo motor, an anemoscope, and synchronous belt. At one of the blade using a servo motor and the left three blades were mounted by driving wheels those connected with the belt synchronously associated, as appeared in Fig.5.a. At the point when the anemoscope assembled the altars of wind direction, the servo motor drive every one of the blades to turn significant edge to preserve the best starting point, accomplishing the conveying the blade according to the wind speed [104].

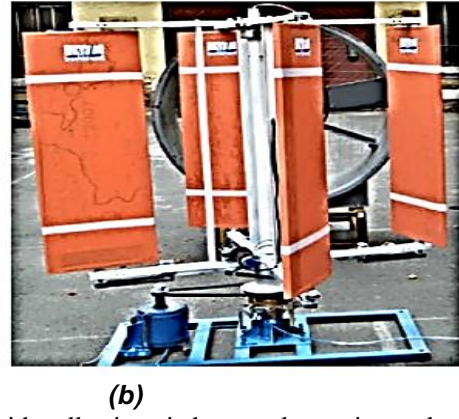
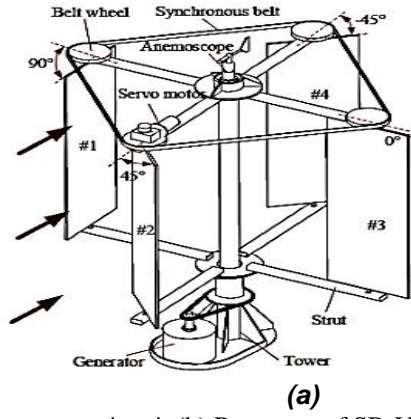


Fig. 5. (a) Schematic concept sketch (b) Prototype of SB-VAWT with collective pitch control experimental setup [104]

The instantaneous angle of attack

$$\alpha_{\theta} = \gamma_{\theta} - \beta_{\theta} \quad \dots\dots\dots(12)$$

The Relative velocity

$$W_{\theta} = V_{\theta} \sqrt{(\lambda_{\theta} + \cos \theta)^2 + \sin^2 \theta} \quad \dots\dots\dots(13)$$

Where γ_{θ} , β_{θ} , V_{θ} are the angle of incidence, local inflow speed and blade pitch angle respectively.

Both α_{θ} and W_{θ} is the functions of azimuth angle θ . For the single blade the instantaneous driving torque

$$M_{\theta} = \frac{1}{2} \rho C H R W_{\theta}^2 (C_l \sin \gamma_{\theta} - C_d \sin \gamma_{\theta}) \quad \dots\dots\dots(14)$$

Where C_l and C_d are lift and drag coefficient, for convenience of comparison, the results are presented in the non-dimensional form [105]. Another side the angle of attack and Reynolds number is derived as

$$\begin{Bmatrix} C_l \\ C_d \end{Bmatrix} = \begin{bmatrix} \cos \alpha_{\theta} & -\sin \alpha_{\theta} \\ \sin \alpha_{\theta} & \cos \alpha_{\theta} \end{bmatrix} \begin{Bmatrix} C_y \\ C_x \end{Bmatrix} \quad \dots\dots\dots(15)$$

Normal force coefficient of airfoil contour respectively and C_x and C_y are the tangential force coefficient along the chord.

Finally, a model for collective pitch control was produced with a variable-pitch system, and four blades of the level profile were used. The length of the blade is 1 m, the span of a model is 0.557 m and, as appeared in Fig.5.b. In this type VAWTs for pitch controlling moving cross-section and self-assertive sliding interface technique were utilized. [1]

- Palash et al. proposed to the prediction the execution of any size and shape of a darrieus VAWT and maintaining the end goal to demonstrate its capability, initially, the expectation from the present model

is checked with arrangement working at the Reynolds number of This VAWT settled pitch control is Shows in Fig. 6(a). [10]

Incorporation of insecure optimal design and dynamic virtual camber impact are basic for exact execution expectation. Rejection of shaky impacts in the investigation brings about an under the forecast of energy coefficient is 36% instead of 10%, when the uneven impacts are adopted. The centrality of demonstrating temperamental optimal design in execution forecast additionally feature the way that the dynamic blade pitching VAWTs make utilization the features of unsteady streamlined for the improved execution contrasted with a settled pitch VAWTs. The avoidance of dynamic virtual camber impact by yourself outcomes is approximately 22% under forecast. In addition, the dynamic virtual camber impact is likely to move the azimuthal circulation of energy about the half upstream which in turn steady with perceptions revealed of this study. Parametric investigations displayed a change in the execution of increasing solidity of VAWT. The solidity is a function of a no. of blades, turbine proportion, and chord length. Increasing solidity of the turbine blades and thus enhances execution at all tip speed proportions. This examination affirms that strength is the fitting non-dimensional parameter to consider the execution of any scale of the turbine, given that the cleared region is kept up. The present system which it utilizes a blend of blade element theory (BET) and double multi-stream tube (DMST) is a solidity device to anticipate the execution of VAWTs with a lift-based mechanism. It can be utilized to comprehend the material science within this mechanism working that makes it appropriate for preparatory design, plan and measuring the size of the turbine for better performance.

The variation in pitch angles is accomplished by 4-bar linkage instrument in crank rocker setup in which ground connection has situated the gathering in the focal center pivot. The turbine with a 4- bladed variable pitch rotor with the mechanism to change the angle of sinusoidal pitching Fig. 6(b) shows. [106]

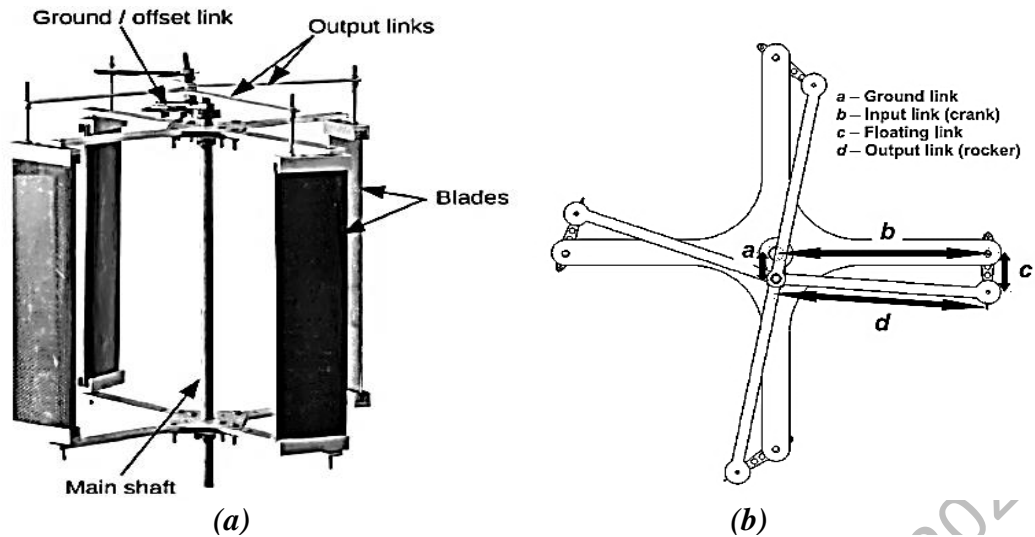


Fig.6. (a) Variable amplitude blade pitching Darrieus VAWT. (b) four-bar linkage mechanism. [10, 106]

- Zhang et al. broadly realized that the nearby stream parameters following up on the blade shift along their round way and vary altogether between the upstream and downstream of the rotor parts, with this respect, to decide the finest feature of the blades to variation of the pitch angle a review was done. In view of double-multiple stream tube display, a streamlining methodology has been fixed up by connecting numerical reformation, which processes the stream over the rotor and to an enhanced in the easiest method of the calculation strategy. In this model of variable pitch VAWT displayed accordingly with respect to Fig.7 [107].

So as to examine and prediction under the precarious stream conditions the varieties of blade pitch angle, this system introduced to improve the streamlined performance of VAWT individual active variable-pitch control model [107].

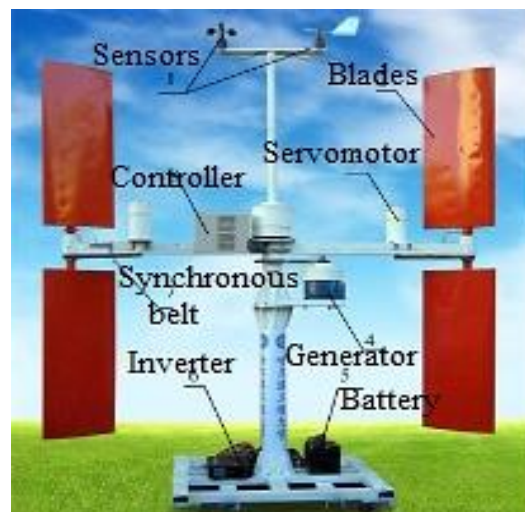


Fig.7. Individual active variable-pitch Prototype VAWT [107]

A demonstration of each blade of the model which can change the pitch angle effectively under control of servo motor. The wind wheel pivoting the blade, for now, concurring wind round to the neighborhood stream field, alongside the azimuthal point, by a servo motor the stance of the blade are varying to accomplish the best-streamlined approach. With the motivation behind getting the greatest power production, the pitching edge of the blade is balanced by a servo motor through synchronous belt Fig.7 shows their proper arrangement.

- Kader et al. assessed 5 kW power straight-bladed VAWT input bolsters forward controller at high wind speeds a pitch control was performed. A novel plan for actuation framework and pitch control has chosen for the VAWT. In that outline, upper and lower sets of the blades are part of two indistinguishable portions are furnished with a solitary solo actuation framework shows in fig.8. [108]

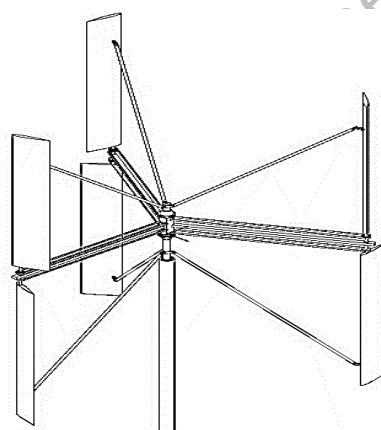


Fig. 8. Displays a 3-Dimensional outline of the design [108].

In this mechanism consider the case in which the lower set is activated with a pitch point of the same size and inverse sense while the upper set is driven with a negative pitch angle. Keeping in mind the end goal to demonstrate the execution of a VAWT and the Double-Multiple Stream Tube (DMST) with variable obstruction factor is received. The DMST show got from the actuator plate hypothesis and depends on the protection of the energy standard. It had been utilized effectively to Darrius rotors anticipate general thrust and torque loads. The primary preferred benefit of DMST display is its constrained calculation time its principle drawback doesn't contemplate dynamic slowdown impacts. Augmentation of the different stream tube models shows by the DMST. It separates into upstream and downstream zones stream of the VAWT. This pitch control framework of novel design permits to

perform freely from the blade azimuthal position and to depend on wind speed estimation just. The wind strike in the downstream zone is thought to be the upstream wind speed. [108]

- Mauri et al. assessed another assembling procedure for the acknowledgment of the blade is proposed of lift based H-Darrieus VAWT. The blade centralized server is given by the arrangement of support structures of intermediate carbon-fibre NACA0021-shaped introduced on a carbon-fibre circular bar, being the blade primary auxiliary part shown in Fig. 9(b). [109, 110], for cover the blade a Clysar material is used as shown in Fig. 9(a). With a specific end goal to, set, up a right, NACA0021 driving, edge, shape, to, the, blade, expanded polystyrene (EPS), material, was received for, its benefit position as far as stiffness/mass proportion. Wind burrow tests above the rated wind speed conditions were done to check the dependability quality of such assembling approach. The Clysar was chosen mainly for its providing a good linkage of the blade coverage, thermo-retraction property. By using Brushless DC drives and a 4 poles 200W motor some initial tests of blade control have been performed. In Fig.9 (b) shows the final design of the wind turbine [111].

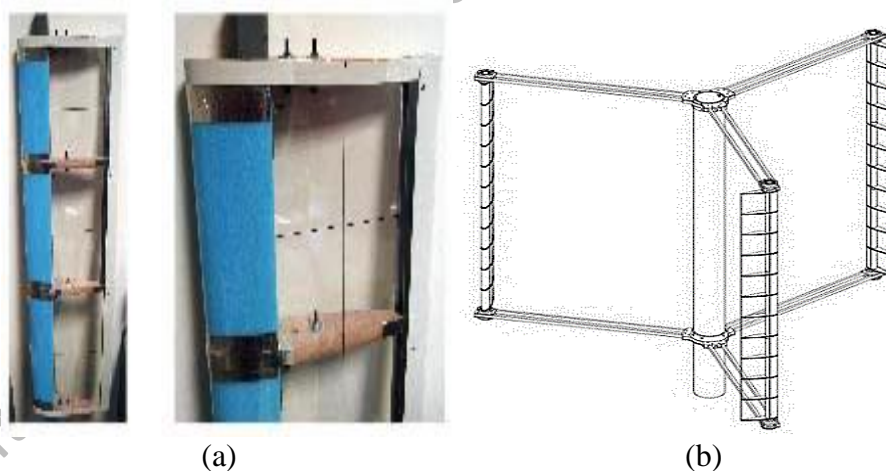


Fig. 9. (a). The blade covered by Clysar. (b) A 3-D overview of the designed turbine [111]

- Liang et al. examine the mechanical behavior of the blade, and after that, the limited environment of the blade should be presented, seen in Fig.10. The blade of the model is essential supported is observed. For wind turbine blade pitch control are introduced a servomotors at the lower struts, prompting about by the mass of blade to an axis force brought, pitch control component and struts. The impacts of axis force couldn't be ignored with the axis forces were supposed to be constant, and the expanding of the length of the blade [112].

Both ends of the blade are performed the variable-pitch blades of the SB-VAWT are essentially supported afterward look into on limit state and at both ends with bearings, which has substantial affects such as deformation, the mechanical properties of the blade, modes and stress. The of wind turbine tower vibrations is eliminate in both from top to bottom and backwards-forwards ways has been examined in different analyses. In,Ref. [113] liang et al. utilized a passive control technique to diminish tower and blade vibrations by disseminating the energy with a tuned mass damper (TMD). It was recommended that a tuned moving ball damper be mounted on the highest point of the turbine to overturn wind prompted vibrations so passive techniques have additionally been considered in different analyses incorporating [114].

For the angular contact the pointed roller or metal ball bearing was utilized for the blade base to hold up under the spanwise loads and the base of blade was viewed as a settled limitation because through servomotor authors control the blade pitch angle. The blade bears its own particular weight, instant, intermittent streamlined burdens and outward constraint. With the wind shear impact overlooked, the streamlined burdens and outward compel were disentangled as a consistently disseminated stack, the accordingly blade was in a state of consolidated distortion of twisting, torsion, and axial force. More concerns were paid on twisting distortion of the blade, it is subsequently four-sided the rosette was utilized to research the crosswise vibration appearances of the blade [112].

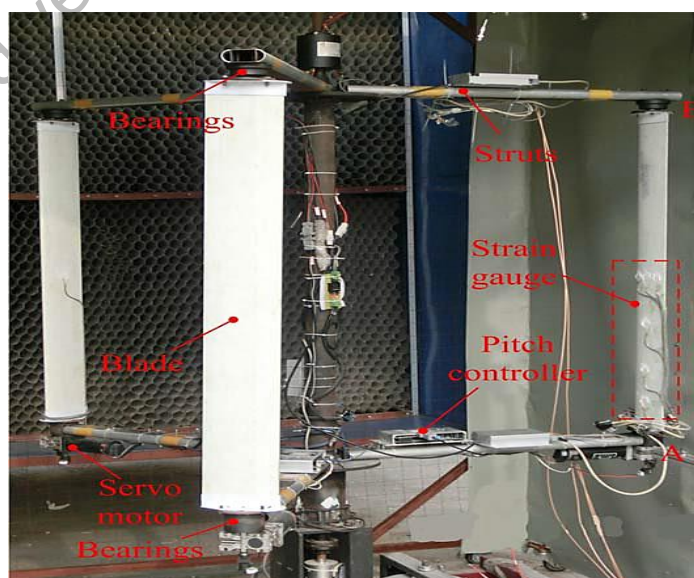
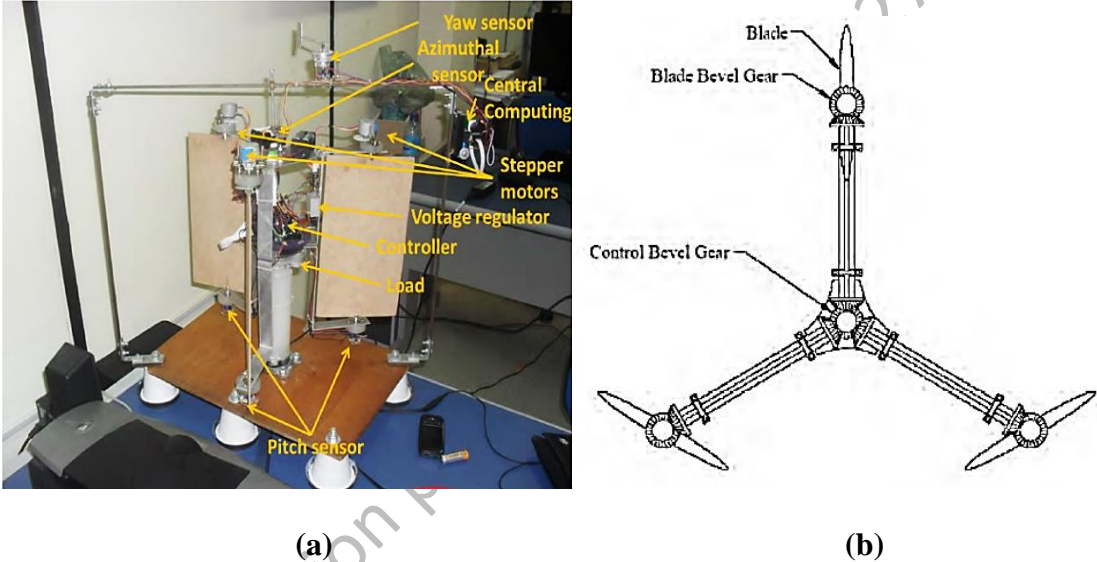


Fig. 10. Lateral vibration and constraint environment analysis for simplicity supported blade [112]

350 • Diaz et al. assessed that the remote mechanical control of the wind bearing yaw and pitch point of ever
 351 blade of VAWT rotor, utilizing an arrangement of incline apparatuses with proportion 1:2, specifical
 352 edge makes one disturbance for every two focal shafts finish upsets. Shown in fig.11 (a) and 11(b) this
 353 model methodology sensibly the streamlined conduct of high solidity rotors if tip speed ratio (TSR) <
 354 1, also, in that condition it can be dismissed the speed losses downwind the rotor [115].

355 The most vital preferred viewpoint of this sort of turbine have high starting torque so that without need
 356 of high wind speeds to let the turbine rotate. In the other hand, the productivity is lower than basic wind
 357 turbines.

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Fig. 11: (a) VAWT prototype (b) Vertical axis wind turbine Conceptual design [115]

• Bhatta et al. proposed the wind turbine blade are furnished with folds that can be freely managed
 for moving camber. Utilizing pitch controls and camber help to make a more prominent constraint
 variance over the turbine than utilizing the pitch control mechanism alone. So this will permit VAWT
 action over an extensive variety of wind speed, enhance resistance to varying wind and allow the turbine
 to self-begin. [116]

Table 2

Summary of a vertical axis wind turbine with pitch control configurations:

S.No.	Wind turbine types	Figure	Features of pitch control system	Merits	Demerits
1.	Three-dimensional VAWT [9]	Fig.3, 4	>The sliding mesh technique	> Simple in construction > Good efficiency	> Tested and designed only for low power applications
2.	Straight-bladed VAWT [104]	Fig.5	> One servo motor >Four belt wheels >Synchronous belt and an anemoscope	>Improving the self-starting capacity of SB-VAWT	> Complicated design
3.	Darrieus VAWT [106]	Fig.6	> Classical four-bar linkage mechanism	>Maximum power extraction for a wide range of tip speed ratios.	> Tested and designed only for low power applications
4.	Prototype VAWT [107]	Fig.7	> Individual active servomotor > Synchronous belt	> Self-starting capability > The maximum power output at any azimuth angle	> Designed and tested only for low power applications
5.	Straight bladed VAWT (Double-multiple Stream Tube) into upstream and downstream zones [108]	Fig.8	> Novel design for pitch control > Solitary single actuation framework > Actuator disc theory	>To perform freely from the blade azimuthal position	> It doesn't take dynamic stall effects into consideration.
6.	Lift based H-Darrieus VAWT [111]	Fig.9	> Classical fixed-pitch concept	>Designed for medium-high tip speed ratios.	> Complicated shape
7.	Straight-bladed H type VAWT [112]	Fig.10	>Blade vibration monitoring method based >Servo motor for individual blades > Simply supported at both ends with bearings in each blade.	> Power coefficient is much larger than respect to the case of 1/4 chord length. > The maximum power coefficient increased from 43% to 49%.	> Complex construction > High cost
8.	Low TSR vertical axis wind turbine [115]	Fig.11	> Two Arduino boards > Used a permanent magnet stepper motor as actuator > A two-axis Hall effect sensor	> Application for low heights VAWTs > Increasing the pitch angle tolerance	> Complex construction
9.	Camber Control for VAWT [116]	Fig.12	> Camber controls > Using a trailing edge flap on each blade	> Creating a greater force > Allows individual pitching	> Tested and designed only for low power applications
10.	CAWT [117]	Fig. 13	> Design of the novel turbine > Six untwisted horizontal blades	> In the unpredictable nature of the wind turbine performance is better > Through both horizontal and vertical mechanisms It can extract wind energy.	> Complicated shape
11	fixed-pitch SBVAWTs [119]	Fig.14	> The blade and the supporting arm used bearings and clips. > The connecting rod and the blade also used clips and bearings.	> High-solidity SBVAWT	> Because of it is a complicated issue so not consider the turbulence flow.
12	A novel blade pitch control [120]	Fig.15	> According to the optimal pitch function a control disc with a rail and three connecting rods controlled the pitch angles of three blades that are designed.	> Optimal blade pitch function for a high-solidity SBVAWT > Smooth uniform movement	> It is a complicated issue > Did not consider the turbulence flow.

In table no. 2 summary of a vertical axis wind turbine with pitch control configurations has been presented.

In fig. 12 schematic top view of the VAWT blade setup has been shown. At least two blades, three, on account of the demonstrated outline, are fixed on a vertical bolster configuration. Then each has a turn that permits singular pitching, revolution about their rotate hub, and a trailing edge fold use for camber control. The trailing edge and pitch fold of every turbine blade has been autonomously controlled by utilizing local actuators.

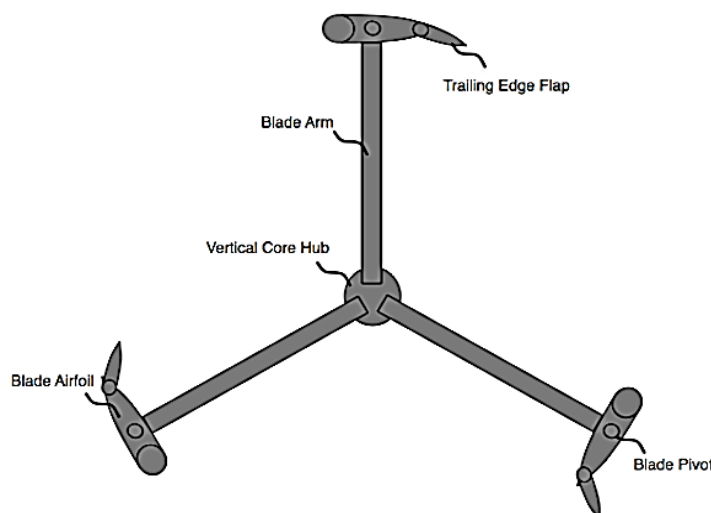
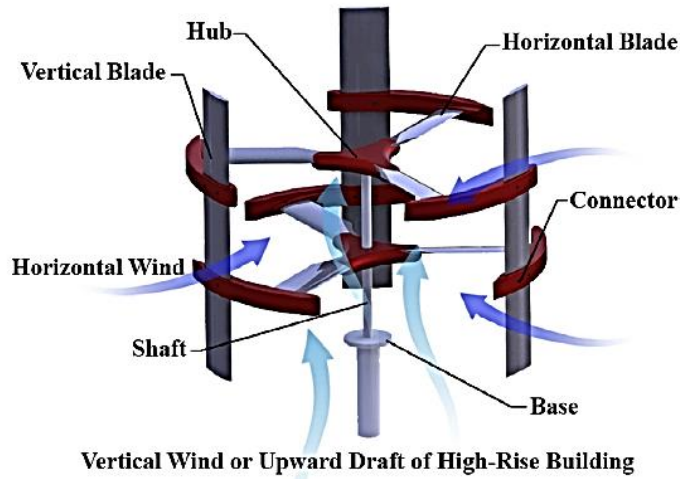


Fig. 12. Individual Blade Controlled VAWT Schematic design [116]

- W.T. Chong et al. proposed a novel cross axis wind turbine has been intellectualized to boost wind power production. This is accomplished by means of outfitting the wind energy from both the horizontal and vertical segments of the approaching wind. The cross axis wind turbine includes three vertical blades and six horizontal blade organized in a cross axis direction. Starting testing utilizing diverters to control the approaching wind speed upward shows in fig.13 (a) that the cross axis wind turbine created critical enhancements in power production and rotating speed execution contrasted with a systematic straight-bladed vertical axis wind turbine. Specifically, it was discovered such the cross axis wind turbine incorporated with a 45^0 redirector delivered a power coefficient of 2.8 occasions larger with respect to the vertical axis wind turbine. Outcome is that the rotor rotating speed was expanded by 70% with more upgraded beginning manner. The CAWT can possibly succeed for urban wind power mechanism the traditional vertical axis wind turbine used because of its capacity to concentrate wind energy regardless of the wind direction, in this manner upgrading the power execution produce [117].



(a)

(b)

Fig. 13. (a) The general arrangement of the cross axis wind turbine illustration is showing. (b) CAWT prototype [117]

In this CAWT the horizontal blades behave as the connecting struts, connecting at the center of the vertical turbine blades through the connectors are shown in fig.13 (b) the top and bottom hubs is linked to a shaft by a comparative height of 10 cm In complete, six connectors linkage the vertical and horizontal blades together [117]. The connecting rods for the CAWT are airfoil-shaped and these horizontal blades are pitched at different angles to observe CAWT performance by the pitch angle effect. Similarly, the top side horizontal blades of the CAWT is at an offset angle of 60° comparatives with the bottom side struts to achieve a further constant power delivery for decreasing the vibration.

- Variable pitch VAWT mechanism diagrams are shown in Fig. 14 suggested by Sagharichi et al. [118]. In this scheme, the pitch angle is to be governed by on eccentricity between the cam and the rotation axis.

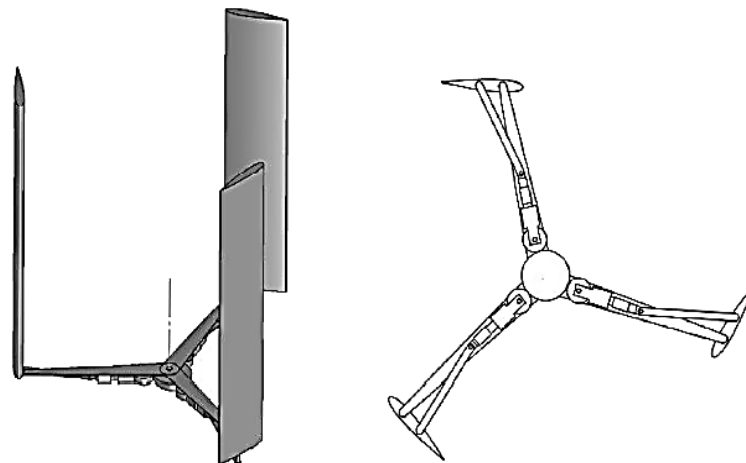


Fig. 14. A proposed variable pitch mechanism schematic [119]

The current scheme inspects the impact of solidity on fixed and variable pitching mechanism of blade of a VAWT. Designed to execute this operation, a VAWT with two, three and four straight blades at five different solidities within the limits of 0.2-0.8 was inspected [119].

- Authors realized that the pitch control device generally comprises a control disc with a considered rail and three connecting rods according to the concentrate shown in figs. 15(a) and 15(b). The rail is considered agreeing to the optimum pitch task those are given, hence that the control compact disk with in the considered rail allows to the optimum pitch angles has been recognized for every azimuth angle. This should be pointed out that from the shapes that at the one end of the supporting rod was connected on the projection other than opposite side through the bearing and clip the blade was connected.

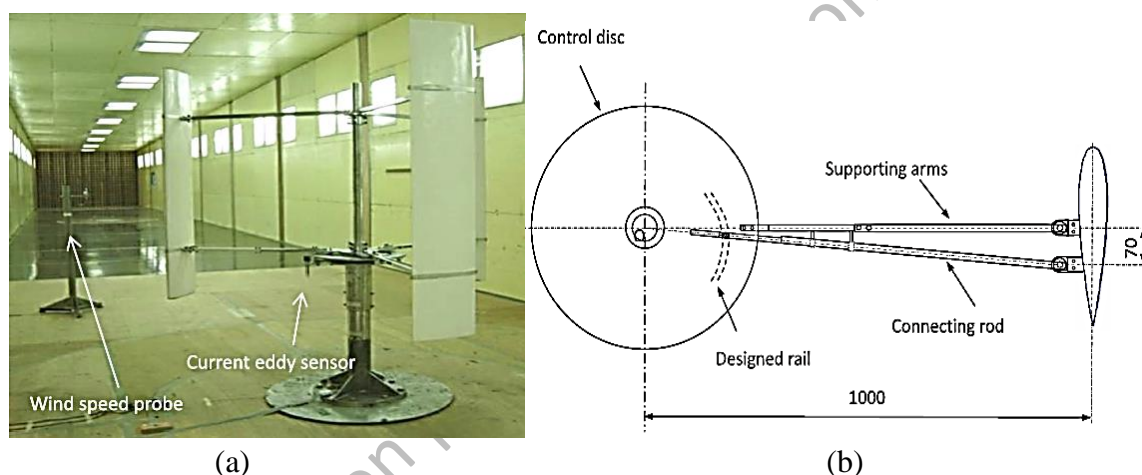


Fig. 15. (a) VAWT model installed in the wind tunnel (b) the pitch control system Sketch [120].

At the end of one the interfacing pole was as well associated with the blade by bearings, clasps and the opposite end could slide inside the hole of the projection and was limited by the considered rail. Through bearings the associating poles were additionally associated with the supportive arms so they could push ahead and in reverse with the mainframe of the supportive arms [120].

4. Conclusion

Vertical axis wind turbine offers economic situation of reasonable energy solution for a remote those area are far away from the incorporated grid lines as well as an urban area for an individual household. Keeping in mind the end goal to spread the utilization of VAWT, the issues connected with different arrangements are poor self-starting, low starting torque and low coefficient of power have been considered. A lot of many

papers in this research area have been reviewed, compared and summarized. Moreover, following conclusions have been drawn from the present survey:

- Variable pitch control technology has made a great development for the self-starting of VAWT.
- VAWT a variable pitch control scheme is more effective than the one with fixed pitch control.
- This paper will work as a guideline to provide useful knowledge and recent VAWT power augmentation technology for researchers in their future studies. From the review, flow augmentation techniques are elaborated on and discussed based on recent research.
- To have automatic pitch control depending on wind speed, servomotor based systems are one of the best options available.
- The variable-pitch control strategy has been analysed to achieve better performances. The pitch control mechanism is feasible, effective and can very well improve the power coefficient and starting torque through offset pitch angle.

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Nomenclature

HAWT	Horizontal Axis Wind Turbines
VAWT	Vertical axis wind turbines
CFD	Computational fluid dynamics
DMS	Double multiple stream
AoA	Angle of Attack
IMC	Internal model controller
IPC	Individual pitch controller
MPC	Model predictive control
PI	Plus integral
CPC	Collective pitch control
ECMPC	Explicit continuous-time model predictive control
TSR	Tip Speed Ratio
BET	Blade Element Theory
DMST	Double multi-streamtube
EPS	Expanded polystyrene
SB-VAWT	Straight bladed vertical axis wind turbine
TMD	Tuned mass damper
CAWT	Cross axis wind turbine
GW	Gigawatt
MW	Megawatt
C_p	Coefficient of Power
μ_o	The operational point of the pitch first component
μ_{ipc}	The operational point of the pitch second component IPC action
μ_{cpc}	The collective pitch control action
U_p	The total pitch angle control action
u^{\min}	Minimum values of the pitch angle
u^{\max}	Maximum values of the pitch angle
α^{\min}	Minimum pitch angle rates of variation
α^{\max}	Maximum pitch angle rates of variation
λ	TSR
ω_r	The rotor angular velocity
R	The rotor radius
μ_∞	Wind speed
\vec{W}	The resultant velocity vector
U	The induced velocity
V	Blade velocity

\vec{V}	The tangential velocity vector
α	Angle of attack
φ	Representing the angle between the vector direction of \vec{V} and \vec{W} .
θ	The azimuth angle
W	The relative wind speed
β or α_p or V_θ	The blade pitch angle
l_c	Blade link
α_c	blade offset pitch angle
α_w	the blade pitch angle amplitude
l_e	The eccentric link
l_m	the main link
l_s	Second-link
\emptyset	the blade azimuth angle
θ_p	The angle between the wind direction and the eccentric-link
d	Turbine diameter,
h	Blade Span
α_θ	The instantaneous angle of attack
W_θ	The Relative velocity
γ_θ	the angle of incidence
β_θ	local inflow speed
M_θ	the instantaneous driving torque
C_l	lift coefficient
C_d	drag coefficient
C_x and C_y	Tangential force coefficient along the chord.
H	The flow mean depth
C	Chord length

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Table 1 The VAWT comparison with HAWT. [94]
(VAWT) (HAWT)

<i>Ideal efficiency</i>	More than 70%	50–60%
<i>Noise production</i>	Quite Less	Relatively high
<i>Self-starting capacity</i>	No	Yes
<i>Whole construction</i>	Easy	Difficult
<i>Blade's action space</i>	Small	Large
<i>Obstacle for birds</i>	Fewer	More
<i>Ground height</i>	Lesser	Big
<i>location of generator</i>	Ground level	Top site
<i>Direction of wind</i>	Multisite	Single site
<i>Yaw control mechanism</i>	No	Yes
<i>Tower sway</i>	Small	Large

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Table 2

Summary of a vertical axis wind turbine with pitch control configurations:

S.No.	Wind turbine types	Figure	Features of pitch control system	Merits	Demerits
1.	Three-dimensional VAWT [9]	Fig.3, 4	>The sliding mesh technique	> Simple in construction > Good efficiency	> Tested and designed only for low power applications
2.	Straight-bladed VAWT [104]	Fig.5	> One servo motor >Four belt wheels >Synchronous belt and an anemoscope	>Improving the self-starting capacity of SB-VAWT	> Complicated design
3.	Darrieus VAWT [106]	Fig.6	> Classical four-bar linkage mechanism	>Maximum power extraction for a wide range of tip speed ratios.	> Tested and designed only for low power applications
4.	Prototype VAWT [107]	Fig.7	> Individual active servomotor > Synchronous belt	> Self-starting capability > The maximum power output at any azimuth angle	> Designed and tested only for low power applications
5.	SB-VAWT (Double-multiple Stream Tube) into upstream and downstream zones [108]	Fig.8	> Novel design for pitch control > Solitary single actuation framework > Actuator disc theory	>To perform freely from the blade azimuthal position	> It doesn't take dynamic stall effects into consideration.
6.	Lift based H-Darrieus VAWT [111]	Fig.9	> Classical fixed-pitch concept	>Designed for medium-high tip speed ratios.	> Complicated shape
7.	Straight-bladed H type VAWT [112]	Fig.10	>Blade vibration monitoring method based >Servo motor for individual blades > Simply supported at both ends with bearings in each blade.	> Power coefficient is much larger than respect to the case of 1/4 chord length. > The maximum power coefficient increased from 43% to 49%.	> Complex construction > High cost
8.	Low TSR vertical axis wind turbine [115]	Fig.11	> Two Arduino boards > Used a permanent magnet stepper motor as actuator > A two-axis Hall effect sensor	> Application for low heights VAWTs > Increasing the pitch angle tolerance	> Complex construction
9.	Camber Control for VAWT [116]	Fig.12	> Camber controls > Using a trailing edge flap on each blade	> Creating a greater force > Allows individual pitching	> Tested and designed only for low power applications
10.	CAWT [117]	Fig. 13	> Design of the novel turbine > Six untwisted horizontal blades	> In the unpredictable nature of the wind turbine performance is better > Through both horizontal and vertical mechanisms It can extract wind energy.	> Complicated shape
11	fixed-pitch SBVAWTs [119]	Fig.14	> The blade and the supporting arm used bearings and clips. > The connecting rod and the blade also used clips and bearings.	> High-solidity SBVAWT	> Because of it is a complicated issue so not consider the turbulence flow.
12	A novel blade pitch control [120]	Fig.15	> According to the optimal pitch function a control disc with a rail and three connecting rods controlled the pitch angles of three blades that are designed.	> Optimal blade pitch function for a high-solidity SBVAWT > Smooth uniform movement	> It is a complicated issue > Did not consider the turbulence flow.

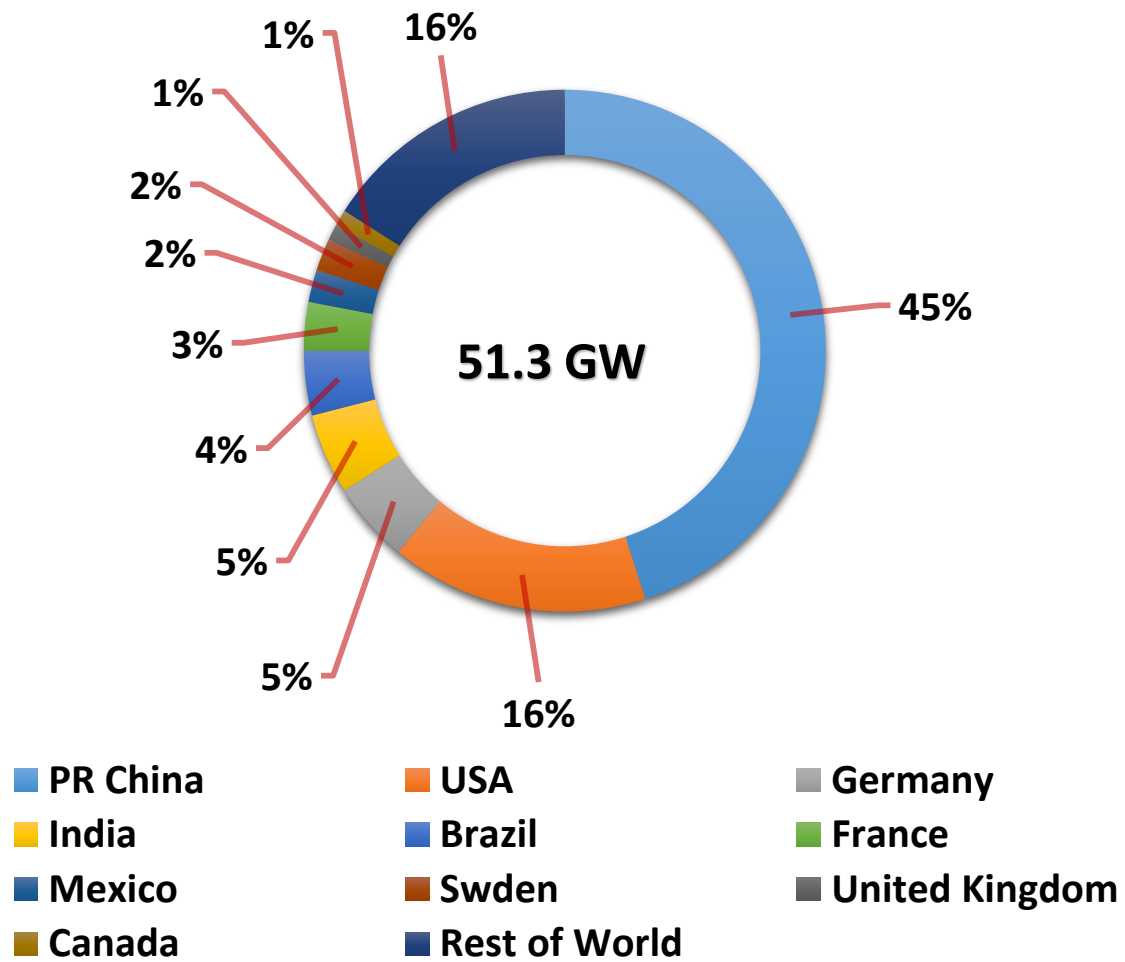
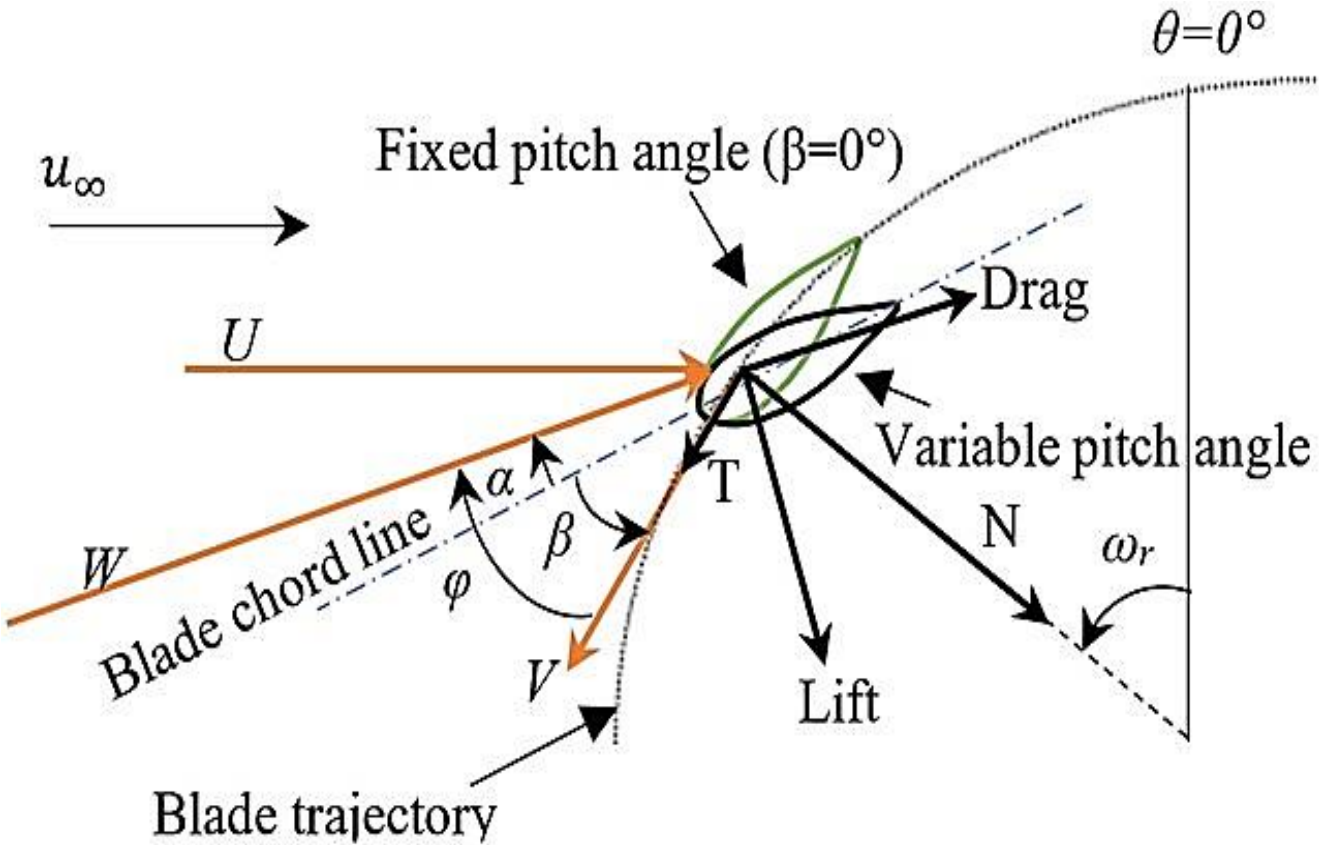


Fig. 1. Global wind industry with 51.3 GW of new wind energy installed in the year 2018 [6].

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Fig.2 Velocities and Forces action on the blade [101]

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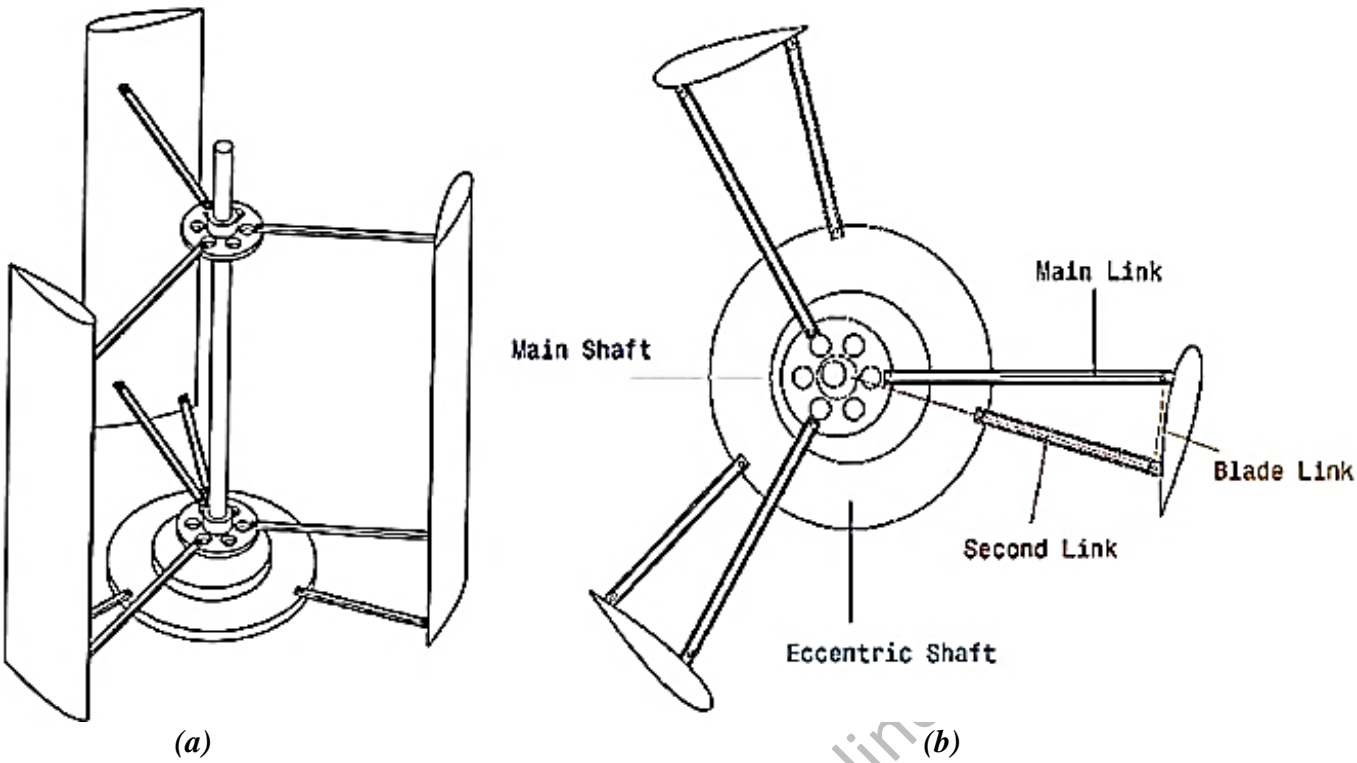
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Fig.3: An overview of the wind turbine modeled (a) Front view (b) Top view of the rotor [\[9\]](#)

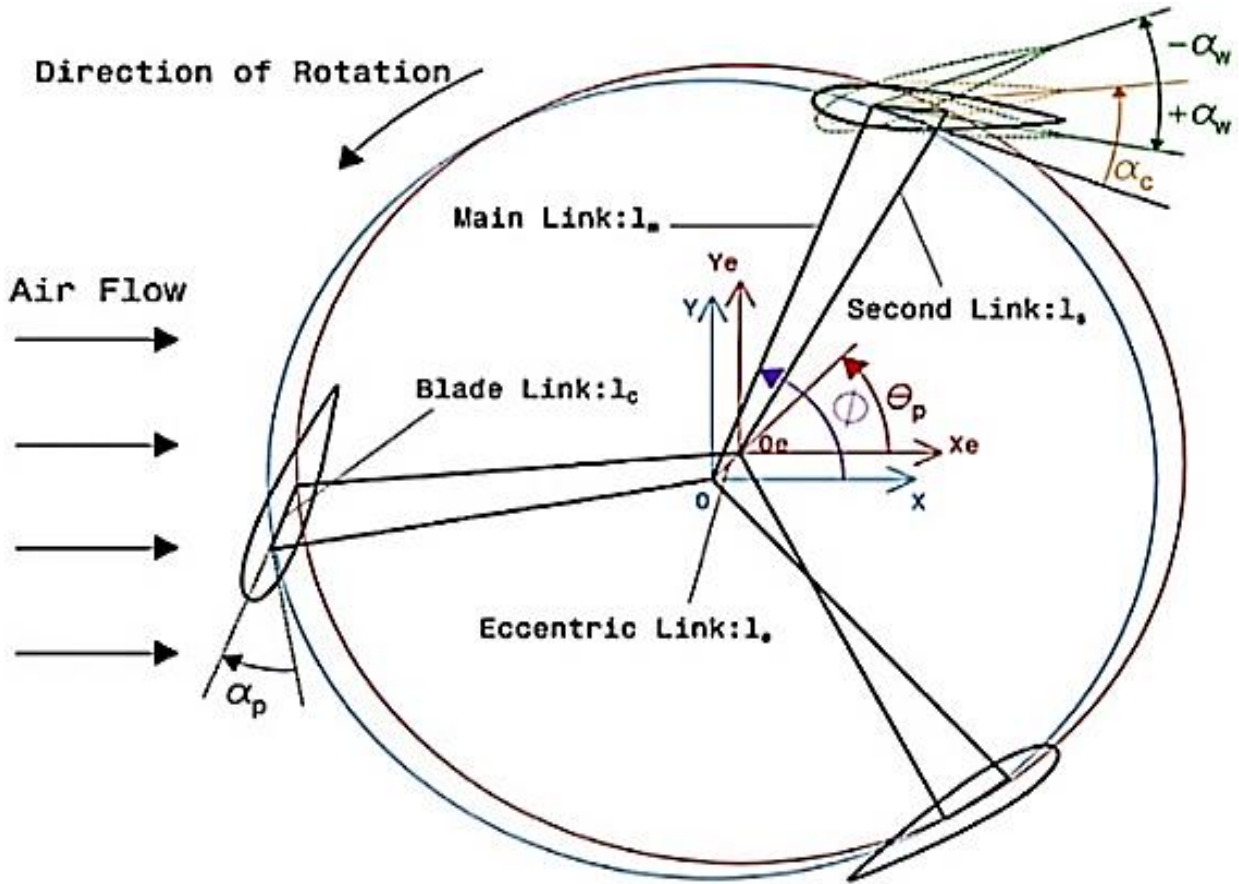
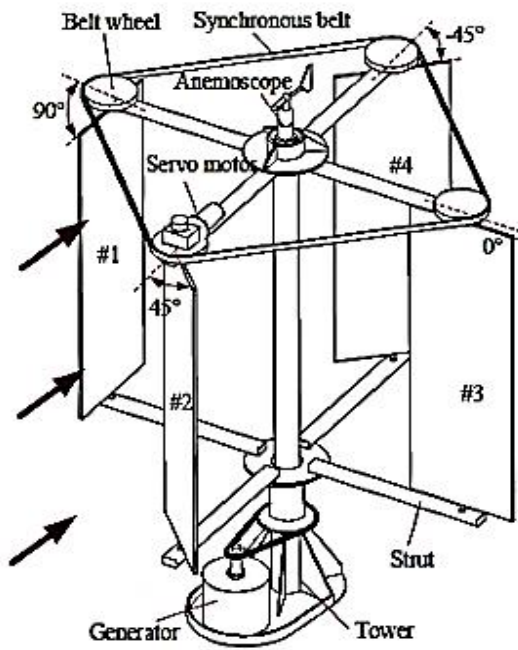


Fig. 4: Schematic sketch of the variable pitch angle system [9]



(a)



(b)

Fig. 5. (a) Schematic concept sketch (b) Prototype of SB-VAWT with collective pitch control experimental setup [\[104\]](#)

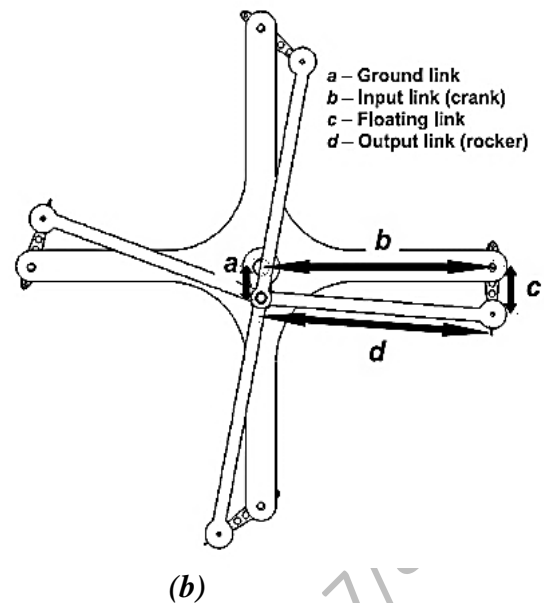
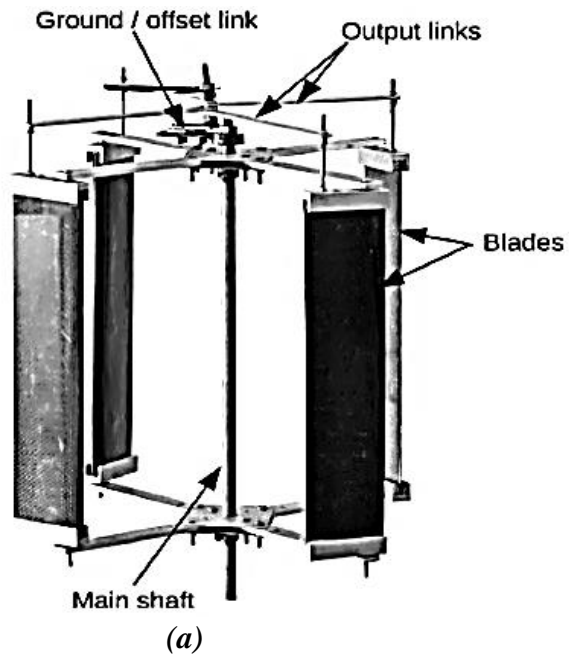


Fig.6. (a) Variable amplitude blade pitching Darrieus VAWT. (b) four-bar linkage mechanism. [10, 106]

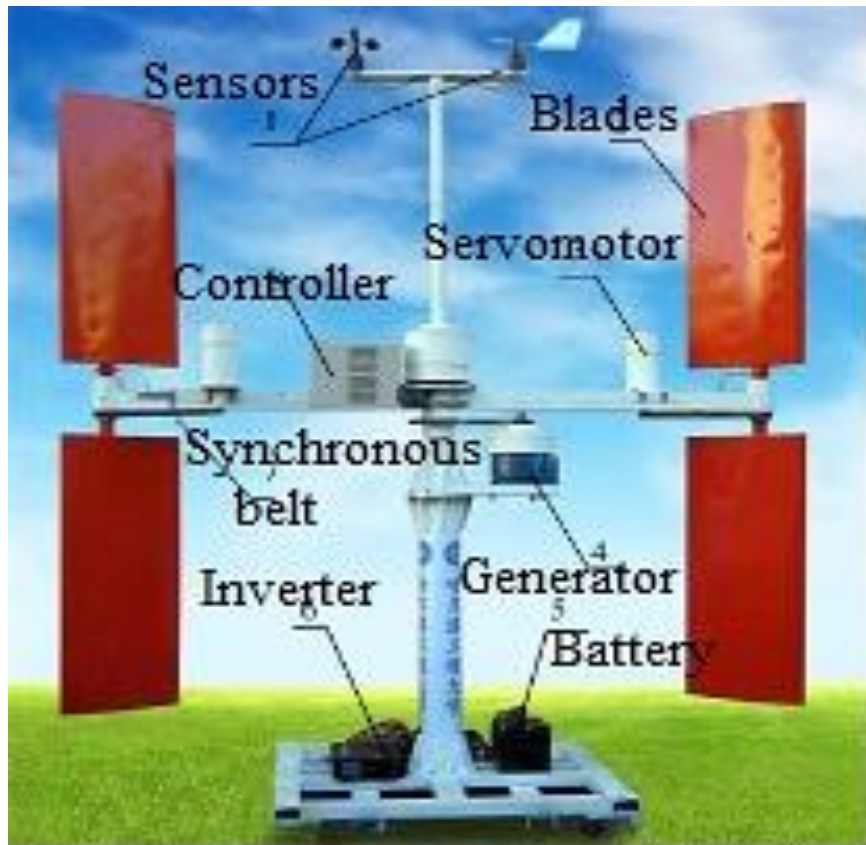


Fig.7. Individual active variable-pitch Prototype VAWT [\[107\]](#)

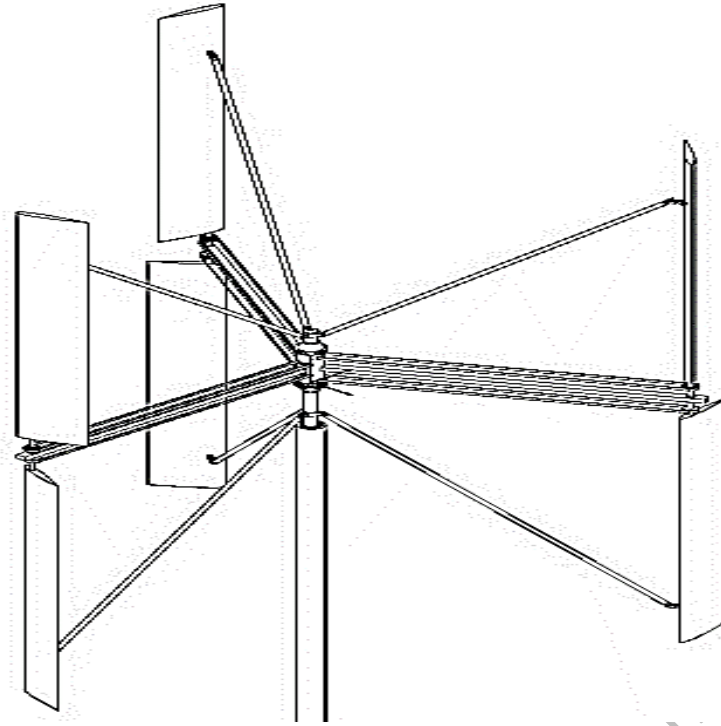


Fig. 8. Displays a 3-Dimensional outline of the design [\[108\]](#).

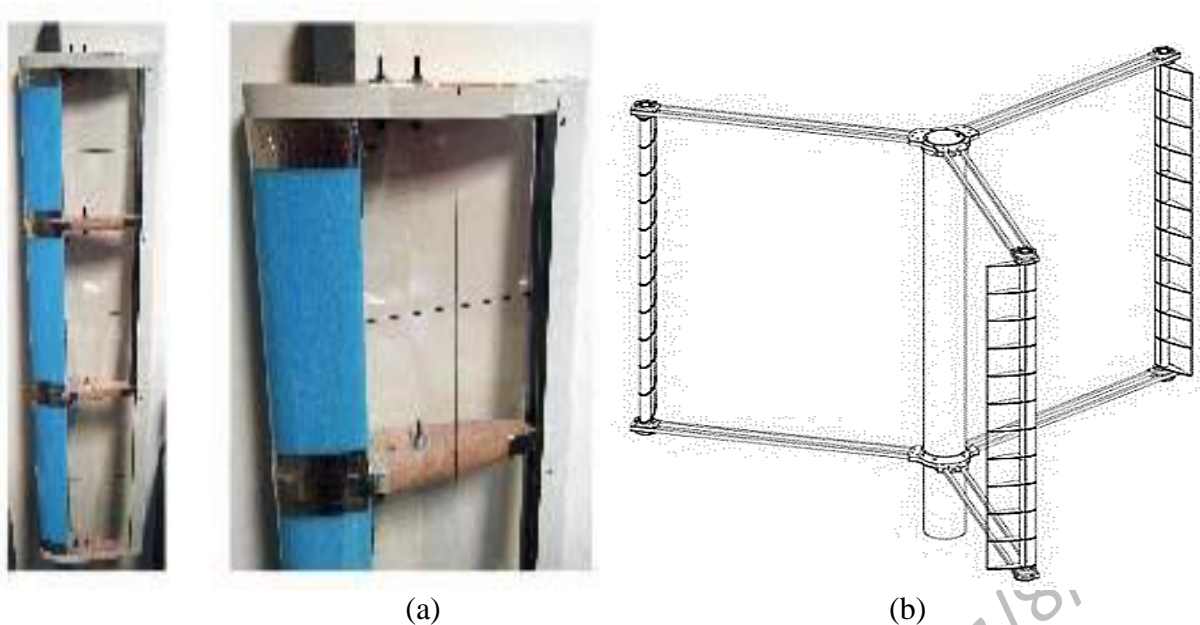


Fig. 9. (a). The blade covered by Clysar. (b) A 3-D overview of the designed turbine [111]

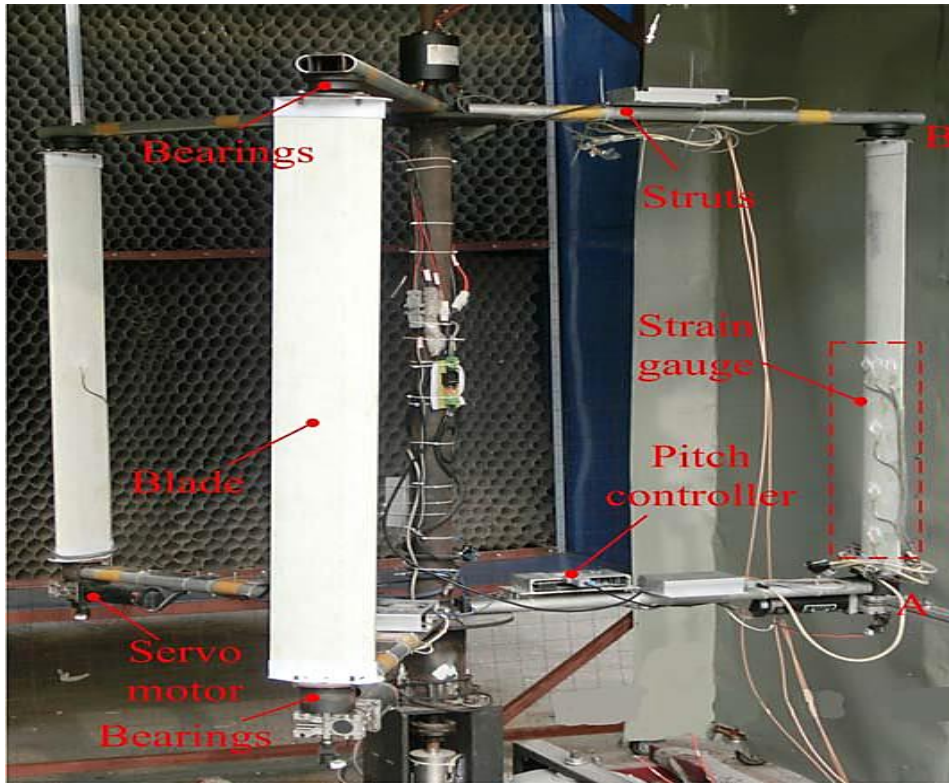
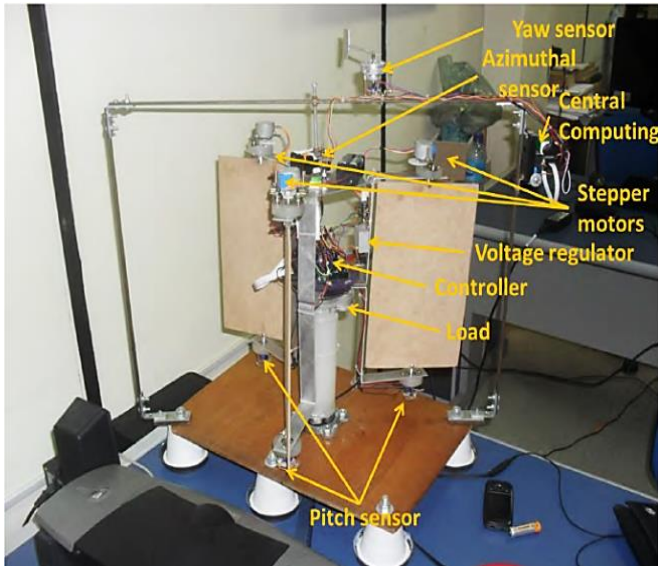
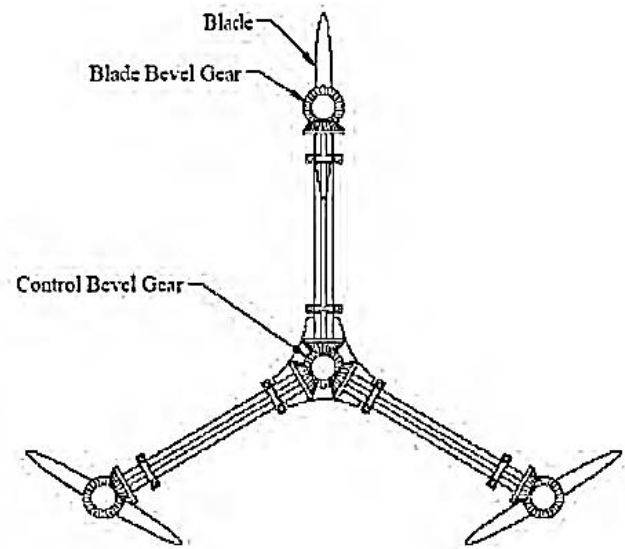


Fig. 10. Lateral vibration and constraint environment analysis for simplicity supported blade [\[112\]](#)



(a)



(b)

Fig. 11: (a) VAWT prototype (b) Vertical axis wind turbine Conceptual design [\[115\]](#)

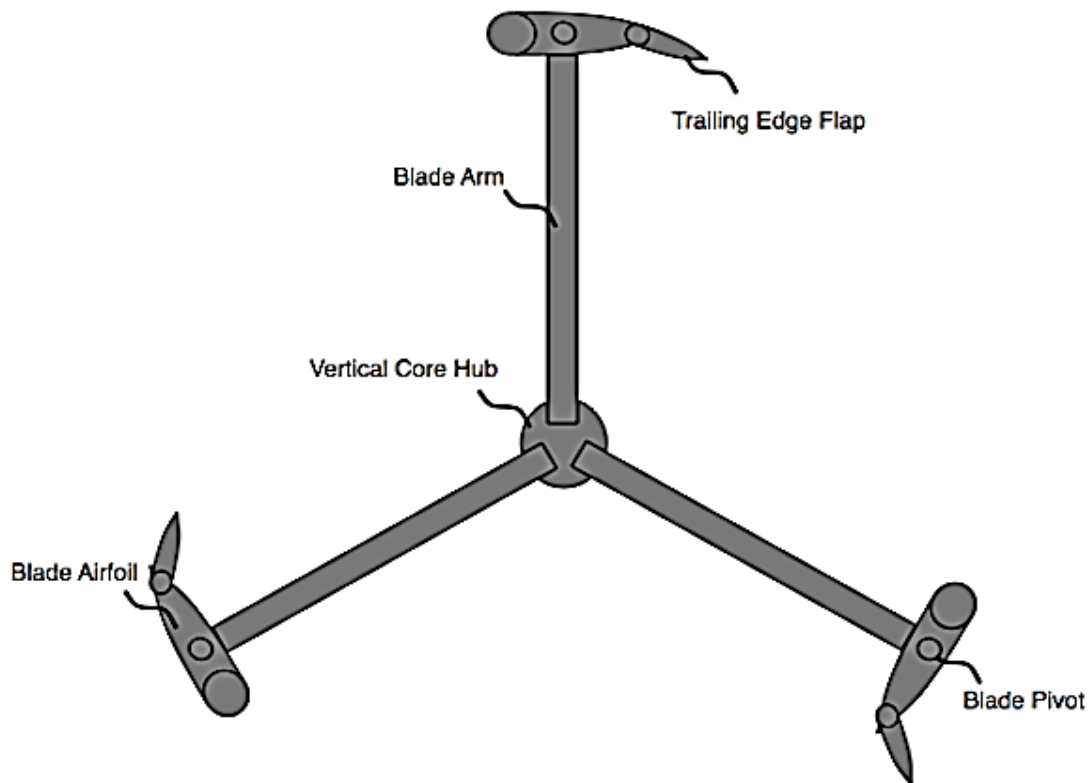
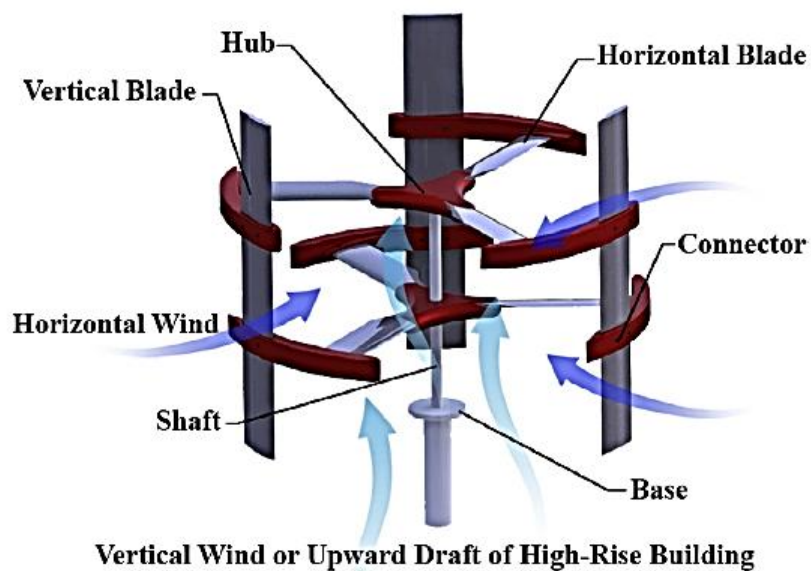


Fig. 12. Individual Blade Controlled VAWT Schematic design [\[116\]](#)



(a)

(b)

Fig. 13. (a) The general arrangement of the cross axis wind turbine illustration is showing. (b) CAWT prototype [117]

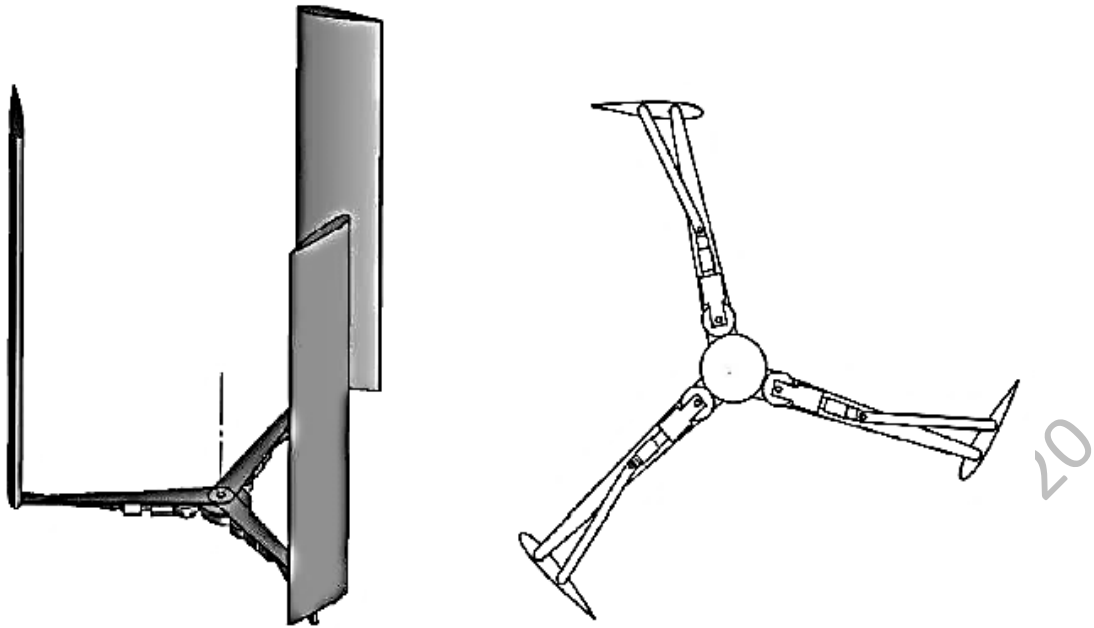
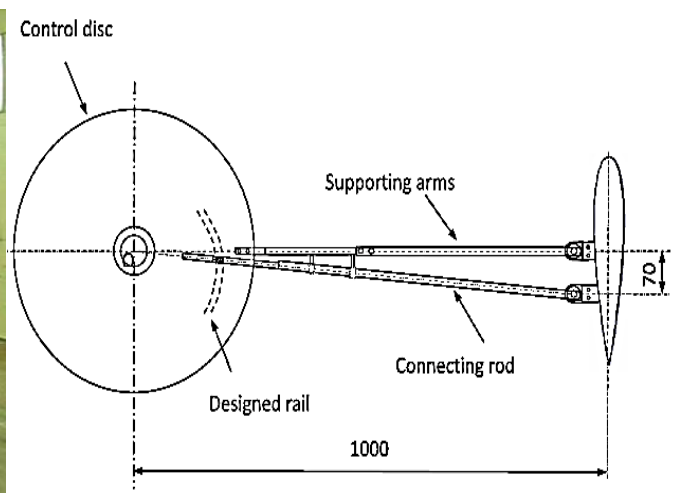


Fig. 14. A proposed variable pitch mechanism schematic [119]

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(a)



(b)

Fig. 15. (a) VAWT model installed in the wind tunnel (b) the pitch control system Sketch [120].

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