Experimental and Numerical Analysis on Small Scale Wind Turbines: A Review

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Abstract:
Nowadays the world is facing problem due to energy crises and rising pollution. The energy production rate is lagging the energy demand. The power generation is mainly dependent on fossil fuels, which is nevertheless having its negative impact on climate. Renewable energy is one of alternative options for eliminating fossil fuel based power production. In the field of renewable energy, wind energy is one of the viable and sustainable resources. Generally big capacity utility scale wind turbines are used for harnessing wind energy. However utility scale wind turbines have certain disadvantages associated with them. Small scale wind turbines have a number of advantages over utility scale wind turbine. Researches are done in the field of small scale wind turbines in the direction of experimental and Numerical analysis. The present review paper gives an idea of the negative aspects of utility scale wind turbine and a review on experimental and numerical analysis done over Small Scale HAWT and VAWT by going through ample number of papers. The findings are concluded with corresponding facts.

Keywords: - Small scale wind turbines, Horizontal axis wind turbines, Vertical axis wind turbines.

Introduction
Presently, pollution and sustainable development is one of the major problems in this world. Pollution due to using fossil fuels is creating adverse effect on the life sustaining over earth wind energy is a promising technology which can contribute for reducing the polluting factors accumulated due to use of fossil fuels. Generally the wind energy is harnessed by using large utility scale wind turbines (USWT) which require a huge amount of financial investment and organizational set up. Small scale wind turbines (SWT) which are with capacity of 1kW or even less have their own advantages. The chief advantages are; small scale wind turbine can be brought and set up by an individual with a small monetary investment and no organizational set up. SWT can be implanted over the roof top of building and the supervision required for that purpose is not of that much degree as required with USWT. However there is no fix threshold limit in regards of any feature of wind mill to separate the utility scale wind turbine from a small scale wind turbine. The small wind turbines rotor are usually 1.5 to 3.5 meters (4 ft 11 in–11 ft 6 in) in diameter and can produce 1-10 kW of electricity at their optimal wind speed [1]. Some units are designed very lightweight in their structure, e.g. 16 kilograms (35 lb), allowing sensitiveness to minor wind motions and a rapid response to wind squalls typically found in urban settings. Some are easily mountable such like a television antenna. In contrast regarding the case of USWT, some researchers have found the negative outcomes of utility scale wind turbines over climate. By exhaustive review it was observed that by deploying large scale wind turbine to get 15-25% power demand of world; it can lead to increment of 1°C of ambient temperature [2]. By surveying for 62 warm seasons, on a particular climatic model and found that it can lead to 1% increase in precipitation rate and occurrence of larger precipitation for the places where large scale wind farms exist [3]. Besides this various researchers have done remarkable jobs in order to enhance the research in development of SWT systems. Teschner and Alterman [4] mainly focused on small-scale wind turbines SWT systems and suggested that the incorporation of corresponding technology within the city requires corresponding mindset both among the officials and
among the city residents. Kamp and Vanheule (2015) presented a review of SWT sector in Kenya in connection with a description of the status of the sector and a more in-depth investigation into the factors and dynamics that hinder sector growth. Mostafaeipour [5] studied the economic assessment of small wind turbine installation for city of Kerman which is in southeastern part of Iran. White et al. [6] advocated that New Zealand municipal council does not have information to understand weather which height limitations may decrease wind-resource utilization by small wind turbines installed in the corresponding areas. By installing a meteorological observation mast in Weno Island, Chuuk State it was found that the yearly energy production of 20 kW by wind turbine is likely to be about 36,841.73 kWh/yr using estimated Rayleigh distribution [7]. By investigating the economic potential of SWT under different urban location points and accounting, it was found that investments in SWT technology by private households in Germany are only economically feasible within exposed areas where the minimum average wind speeds is around 4 to 4.5 m/s [8]. A techno-financial evaluation for two Chilean locations revealed that the ‘Net present cost’ exhibited itself as more sensitive to the price of buying energy from the grid as well as to the annual average wind speed [9]. By investigating on the wind energy potential of Incen region in Ankara-Turkey, the suitability of small scale wind turbine energy production was found [10]. Messino and Culotta [11] reported that the various parameters i.e., wind profiles, installation height, land use, characteristics of the turbine can influence the energy production of SWT. They brought to notice that the opportunity offered by the Italian legislative framework can enhance to pay more attention to a new potential market i.e. the SWT in urban areas. [12] By performing the feasibility study of SWT for 88 regions in Iran it was found that approximately 30% of the studied regions were suitable for the cost-effective use of SWT. [13] It was studied and found that for past few years, renewable energy sources have been in a state of continued growth. In connection with all the green energy branches, wind turbines have experienced the fastest expansion in Poland state as well as in subparts of Europe in connection with SWT. [14] An on-going experimental campaign carried out over a small size vertical axis wind turbine in the facility of the Savona Harbor. Investigations mainly concern two issues: power production assessment and full-scale structural behavior. Results obtained indicated suitability for improving future installations of SWT. Whale et al. [15] expressed that rigorous testing of SWTs is required in order to ensure safety, reliability and performance of SWT technology. Author presented a Numerical modeling of wind resource at the Australian National Small Wind Turbine Centre (NSWTC) test site to give insight into the scope and scheduling of power performance tests accompanied with testing completion requirements for SWT performance standards. For the corresponding model the results indicated that testing standards needs to specify more than 10 min worth of data in each bin in order to reduce uncertainty errors in power curves, particularly at higher wind speeds and during furling and unfurling of the turbine. Nazir et al. [16] designed a microgrid model and showed that with approaching the peak load capacity of 152kW the lowest energy cost and greatest reduction is CO2 emission takes place. Mishnaevsky [17] investigated the performance of small wind turbine fabricated by timber in Nepal. His study culminated that the timber of Pine and Lakuri haves opportunity of availability, less expensive cost and haves mechanical properties like high stiffness and breaking strain which could be the best for fabrication of wind turbine system. Adhikari et al [18] investigated the possibility of using bamboo in a triangular lattice towers which can be used with small wind turbines. To examine the feasibility, experimental tests on bamboo's material properties and design analysis of a 12 m elevated bamboo tower for a 500W wind turbine was carried out. In the experiment essential properties of a typical bamboo species for structural analysis of the tower have been determined. Analytical and finite element approach has been taken for analysis. Fig.1 represents the free body diagram (FBD) of the tripod model of bamboo lattice tower. The result of the study demonstrated the high degree of feasibility of designing bamboo lattice towers for small wind turbines, which shows hopeful cost reduction potential for small wind turbine towers in connection of developing countries.

![Free body diagram (FBD) of the tripod model of bamboo Lattice tower](image)

Going through the number of papers which represents the researches carried out in entire world in the direction of SWT development; this paper represents an overall review in the field of performance analysis experimental and numerical and
other connected developments in the field of small scale wind turbines.

2. Classification of small scale wind turbines:
Small scale wind turbines can be broadly classified into two types i.e., horizontal axis wind turbine and vertical axis wind turbine which is same as that of utility scale wind turbines as shown in Fig.2 represents the broad way of categorization of wind turbines. Horizontal axis wind turbine (HAWT) is generally lift type turbo machine with 3 blades. Vertical axis wind turbine (VAWT) can be subcategorized into two ways i.e. a drag machine or a lift type machine.

![Fig.2. Classification of small scale wind turbines](image)

The lift type machine is the one in which the blades of rotor moves by lift principle of moving wind. This kind of machine requires aerofoil shape of blade. While drag type machine does not require aerofoil shape and the drag principle of moving wind over the blade is used for spinning the rotor. Three bladed horizontal axis wind turbines are most common type of machines used in the world while Vertical axis wind turbines are limited to develop power in small scale generally for household power requirement.

3. Horizontal axis wind turbine (HAWT):
A Horizontal axis wind turbine is the one in which the axis of rotor remains in horizontal direction parallel to the surface of earth. Today HAWT is the most commonly used sort of wind turbine around the world. The forces of the blade of the rotor are due to lift applied on the aerofoil shape of the blade of the rotor. The commonly used type of HAWT is three bladed HAWT. The two types of HWAT’s are onshore and offshore. The Onshore HWAT’s are the units implanted over the seashore where the wind blow is in plenty with sufficiently high speed. The offshore type of HWAT is the one which are implanted on the areas other than the coastal areas where the wind velocities are in favor. Many researchers have done noticeable jobs in the field of SWT of HWAT types.

3.1 Experimental analysis on small HAWT:
Various researchers have designed and developed the physical models or prototypes of small HAWT to evaluate their performances for specific environmental conditions. Summary of major experimental researches carried out on small HAWT is presented in Table 1.

<table>
<thead>
<tr>
<th>Literature</th>
<th>Specifications</th>
<th>Test conditions</th>
<th>Outcomes/Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hirahara et al. [19]</td>
<td>Rotor diameter -500 mm</td>
<td>Wind turbine system used - µF500</td>
<td>• The net efficiency and power coefficient were derived to be 0.25 and 0.36 on average.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Maximum $C_p$ was found about 0.40 with tip speed ratio 2.7 m/s</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>• Illustrated the technical concepts of high wind operation and safety.</td>
</tr>
<tr>
<td>Matsumiya et al. [20]</td>
<td>Rotor diameter -1.8 m, Blade material- Carbon fiber, Blade mass -380 g per blade, Rated/maximum powers-1 kW at 12.5 m/s and 3.2 kW at 20 m/s Generator-Permanent magnetic, three-phase synchronous type Brake- Stall regulation and electromagnetic brake with Yaw control Swing rudder</td>
<td>Three-bladed upwind-type, Cut-in/cut-out wind speeds-2.5 m/s - 12.5 m/s</td>
<td></td>
</tr>
</tbody>
</table>
Nishizawa et al. [21] 
Diameter of Rotor 1m, Blades – 5, Solidity -0.26 and 2 types of tail fins (large and small).
The yaw moment was measured at rotational frequency of 0 rpm, 100 rpm, 200 rpm and 300 rpm.

Kishore et al. [22] 
Three-bladed, 39.4cm diameter, blades linearly twisted by 32° from root to tip, Angle to hub 3°. The airfoil used was dissymmetrical along the camber line and had maximum thickness of 6.5mm throughout the span of the blades.

Wind speed ≤5m/s

Cut-in wind speed of 2.7 m/s produced 0.83W of electrical power.
Maximum Cp 14% occurred at the tip speed ratio of 2.9.

Ladje and Sadeghi [23] 
NREL's baseline 5 MW wind turbine, blade length of 0.4 m

Wind speed range - 2 m/s and 22 m/s with a turbulence intensity of less than 1.0%

It was found that the blade twist had a significant influence on the observed instability: a blade without a twist experienced a strong subcritical instability.

At low wind speeds, increased turbulence appeared to increase energy production, at wind speeds near the turbine furling speed; elevated turbulence resulted in decreased energy production.

Pagnini et al. [25] 
Nominal power -20 kW
Maximum power -22 kW
Turbine diameter -10 m (height = 5.8 m)
Generator –Synchronous permanent magnets
Power regulation -Active yaw hydraulic brakes

Max. rotational speed -90 rpm,
Cut-in wind speed 2.5 m/s,
Nominal wind speed -12 m/s,
Cut–out wind speed- 20 m/s

SWT turn out to be very sensitive to the ambient turbulence conditions, not adequate for installation in complex areas where turbulence is often very high.

Shen et al. [26] 
3 bladed upwind 600W small wind turbine rotor with a diameter of 1.8 m.

Average wind speed of 10 m/s was. The cut-in wind speed was 4 m/s and the cut out wind speed was 20 m/s.

Wind turbine blades with properly designed 3- dimensional stacking line can increase the annual energy production and have a better starting behavior compared with 2- dimensional-optimized blade geometries

Selig and Mc Granahan [27] 
Turbine with aerofoil E387, FX 63-137,S822, NREL S834, NREL SD2030 and SH3055
Reynolds numbers of 100,000, 200,000, 350,000 and 500,000 for both clean and rough conditions. In some cases, 150,000

Wind speed of 8.40m/s

Collectively the performance data presented.

Jugsujinda et al. [28] 
Rotor diameter-120 mm

Efficiency of 9% was found.
Hadrami and M [29]  
Airfoil- NACA 0012  
Diameter-1.2 m  
Root cutout- 0.3R  
Chord-0.08 m  

MAAE test conditions -  
The 25cm diameter MAAE rotor was operated at λ≈6 through out a Reynolds number range of 3620 to 30,100

Scaled TU Delft test conditions  
The scaled TU Delft rotor was operated in the water channel at λ≈6 and λ≈8 with Reynolds numbers ranging from 12,800 to 31,400

- HAWT’s were found to be more efficient than VAWT’s.

Hong et al. [30]  
The performance of the wind turbines was evaluated through a three-phase alternating current permanent magnet synchronous generator (PMSG). The PMSG consists of an internal rotor with a permanent magnet and external stator. The external diameter of the PMSG is 168 mm with a thickness of 98 mm for a 300W output.

- The wind power system developed in this research can generate 2497 kW/year-system electricity by utilizing a wind energy technique with a livestock ventilation fan that emits artificially created, consistent, high-speed airflows.

Nishi et al. [31]  
For Both Rotors common  
Tip radius- \( r_t \) 0.25 m  
Hub radius-\( r_h \) 0.07 m  
Number of blades: 3  
Airfoil -MEL031  
Tip chord length-0 mm 33.3 mm for Rotor A and B respectively  

Wind velocity- 8m/s  

- In Rotor A, the maximum output tip speed ratio agreed with the design value, but the maximum power coefficient decreased significantly in comparison with the design value.

- In Rotor B, the maximum output tip speed ratio was low when compared with Rotor A, but the maximum power coefficient increased by approximately 38.7%.

Kosasih and Tondelli [32]  
NACA 63-210 airfoil profile  
The rotor diameter is 190mm  

The turbine was placed in a wind tunnel with working section of 450mm x 450mm x 1500mm. The wind tunnel is capable of producing wind speed up to 25ms\(^{-1}\)

- The coefficient of performance of the micro wind turbine increased by approximately 60% with the addition of simple conical diffuser, and 63% with the addition of nozzle conical diffuser.
3.2 Numerical analysis on small HWAT:

Besides experimental approach various researchers had been performed for numerical approaches in the field of HWAT. Numerical approaches have their own importance as by simulation analysis the performance of SWT can be examined. Tabrizi et al. [33] compared the turbine blade load statistics for inflow turbulence fields based on the open terrain standard Kaimal spectra, (suggested in the standard IEC61400-2 that covers the design and safety standard of small wind turbines) and measured turbulence spectra from a built environment site. The findings showed that for extreme, high turbulent intensity winds, the measured spectra predict isolated loading events around twice the magnitude of loads predicted by use of the standard spectra. They also concluded that there is the need of improvements in the standards in order to model the non-Gaussian wind statistics that occur in extreme events such as sudden strong gusts. Wata et al. [34] did a research in which a low Reynolds number airfoil was designed and tested for use in small HAWTs. Study using XFOIL and wind tunnel experiments were performed on the new airfoil at various magnitudes of Reynolds numbers. The pressure distribution, the power coefficient (Cp), the lift and drag coefficients, CL and CD, were studied for different angles of attack i.e. α. It was found that the airfoil can achieve excellent aerodynamic characteristics with varying Reynolds numbers and can be used as an efficient airfoil in small HAWTs. Fig.3 represents The Lift coefficient (CL) of the tested airfoils against α for Re = 38000 and Re = 205000.

Fig. 3. The CL of the tested airfoils against α for Re = 38000 and Re = 205000. [34]

Duquette and Visser [35] did a numerical study to examine the impact of blade number and rotor solidity on the aerodynamic performance of small wind turbines. Blade element momentum theory and lifting line based wake theory were employed to parametrically assess the effects of blade number and solidity on rotor performance. It was found that increasing the solidity beyond what the traditional magnitudes used for wind turbines lead to increased power coefficients at lower tip speed ratios, with optimum range between 3 and 4. Bai et al. [36] studied the BEMT approach to design the regional turbine blade for a 10 kW HAWT suitable for the area of Tainan and Taiwan. The wind energy potential in the area was first analyzed through the Weibull wind speed distribution method. The resulting monthly average wind power density was then adapted to the BEMT design of the blade. Mathematical models were developed to allow the calculation of lift and drag coefficients for S822 and S823 airfoils. The models were then combined with BEMT equations to calculate the aerodynamic performance of the resulting turbine blade. The CFD approach was also applied for the simulation of aerodynamic performance and compared the results with those obtained using BEMT. The results of the two methods (CFD and BEMT), including mechanical torque, thrust force, mechanical power, and power coefficient, were found in perfect agreement at wind speeds of 4 to 16 m/s with the TSR between 5 and 10. Freere et-al [37] had done an experiment and studied with a low cost wind turbine model i.e. MG4520. The overall study culminated that a big potential exists to improve the performance of horizontal axis wind turbine and needs alterations of controller and generator to improve the aerodynamic performance of an upwind, three-bladed, small HAWT. The aerodynamic performance curves showed that for low speed tests, a maximum power of 470W is obtained at 9 m/s. Blade fabrication was done by Lissaman [38] and found that a small degree of roughness is vital with aerofoil blade with low Reynolds Number for better performance and efficiency. Henriquins and Silva [39] fabricated a new aerofoil whose performance was observed performing well in urban environment. Habali [40] fabricated and tested the blade and blade rotor which was a grouping of two aerofoil’s as a combination of two airfoils FX66-S-196 and NACA 63-621. The study revealed that the cut in and rated speed for corresponding wind turbine are 5 and 10 m/s, respectively. Similarly the rated power was found 16 kW and had gone beyond the installed generator capacity (15 kW). Menegozzo et al. [41] Developed a numerical model of HAWT under gust conditions has and successfully validated, against the NREL Phase VI measurements by using an unsteady CFD simulations with unstructured moving mesh. The analysis showed that CFD approach is a reliable solution to study 3D phenomena, which affects the wind turbines during their operation under gust conditions by requiring only rather small amount of experimental data.

Marti et-al [42] presented an MILP model to optimize the design of rural electrification systems which uses wind energy. The model was developed considering the particular
characteristics of projects in the Andean region of Peru, similar micro wind electrification projects are used in other rural areas of other regions and other countries. The solutions defined the location of the generation point in the village and also the microgrid design. The model also provided the location as well as sizing of the other equipments involved in the projects (Controllers, batteries, inverters and electric meters). As input data, it considered the amount of energy that a wind turbine placed at a particular point will produce and the requirement of the consumptions points, in terms of energy and power. The optimization objective was to minimize the initial investment costs to meet the demand. Scappatici et al. [43] had suggested a laboratory to market kind of approach for designing of blades of small wind turbines by numerical analysis. The choice of blade profiles is based on the optimization of the aerodynamic behavior and compatibly with limitations due to the requirement of a simple mechanical structure. A plot was reported of the experiment between RPM and power curve, as measured in the wind tunnel facility, for different values of wind intensity. It was found that there are wide intervals of RPM characterized by substantial stability in regards of power outcome. The experiment supports the choice of the five blades as a response to high levels of turbulence intensity. Pourrajaban et al. [44] had studied to develop a methodology for the aero-structural design including the consideration of the starting of a small wind turbine blade. To design a fast-starting blade, starting time was accompanied with output power within an objective function while the blade allowable stress was considered as a constraint. The output power and the starting time were calculated by the help of blade-element momentum theory and simple beam theory was employed to compute the stress and deflection magnitudes along the blade. A genetic algorithm and stress limitation concept was employed. Considering the starting time in the objective function the analyzing method was found useful because it lead to a notable reduction of the starting time in return for a small drop of the output power. It was also found that in comparison with the blade designed only for the output power, an increment in the chord and twist distributions in the hub region is needed to decrease the starting time of the blade. N.A Ahmed [45] conducted a computational simulation study and a wind tunnel test over a novel small scale wind turbine and advocated the viability of the same for domestic and industrial application. Wekesa et al. [46] performed a numerical approach to investigate wind energy potential under unsteady conditions. In carrying out the study, the wind characteristics for two rural-urban towns in Kenya, namely Garissa (0°28'S,39°38'E) and Marsabit (2°19'N, 37°58'E), were selected. A CFD analysis method was used to estimate both unsteady wind inflow performance and the flow characteristics that affects the performance on (VAWT). By using the validated CFD model, unsteady wind simulations were performed and the results obtained were compared with corresponding empirical methods. Compared to the prevailing methods, the proposed numerical method was found not only computationally inexpensive, but also robust for both the cases i.e. steady and unsteady wind conditions. Gagliano et al. [47] had done a research and found that among all renewable energy sources, the electrical power generation from micro-wind turbines has its huge potential especially in urban settings. By increasing the spread of micro-wind turbines not only promotes the decentralized generation of energy, but also helps to tackle fuel poverty and to accomplish reductions in the emission of greenhouse gases (GHGs). The work proposes an innovative methodology to make use of wind flow fields, calculated by means of computational fluid dynamic (CFD) codes in urban environments, within the geographical information system (GIS) platform. The test was conducted by subjecting the wind turbine with the SWT. The corresponding numerical results approved well with experimental results at higher Reynolds numbers with output C_t values close to 1.7.

4. Vertical axis wind turbine (VAWT):

The VAWT is the one in which the axis of the rotor is normal to the earth surface. There are two types of VAWT i.e. drag type VAWT as shown in Fig.4 (a) in which the rotor gets the torque by drag force of flowing wind and the other one is lift type VAWT in which the rotor gets the torque by the lift principle of air as shown in Fig 4(b) . The Savonius and Sistan type models are drag machines while Darrieus rotor is the lift type wind machine.

![Fig.4. (a) Savonious Rotor  (b) Darrieus Rotor](Image)

Same like SWT –HWAT, the researchers have done remarkable jobs in the field of VWAT. Didane et al. [48] studied the development and aerodynamic performance prediction of a unique contra-rotating vertical axis wind turbine (VAWT). The
The purpose of the study was to investigate the effectiveness of adopting the contra-rotating concept to a VAWT system while enhancing its conversion effectiveness. The performance evaluations of the corresponding model were established in terms of key aerodynamic performance parameters i.e. power, torque, power coefficient and torque coefficient. The systematic analysis of these quantities showed the effectiveness of the contra-rotating technique on VAWT system and the ability to extract additional almost threefold power over the entire operating wind speed ranges covered. Subramanian et al. [49] presented in their paper a study on the effect of solidity and airfoil profile on the performance of Vertical Axis Wind Turbines (VAWTs). It was found that two bladed VAWTs generated more power than the three bladed turbines and the turbines with lower solidity perform better at high λ. Ali et al. [50] investigated the design of a Savonius wind turbine (VAWT) and its potential to generate power with it. To improve the performance of the turbine, a flow restricting cowl was incorporated with the turbine. The airflow performance of the turbine was investigated both experimentally and computationally. Under varying conditions, the cowl showed a significant improvement compared to the bare rotor at all speeds.

Fig.5 represents the picture of savonius wind turbine with cowling [50]. Danao et al. [51] did an experimental investigation on a wind tunnel for small scale vertical axis wind turbine with unsteady wind conditions. The wind speed at which testing was conducted was kept 7 m/s (giving a Reynolds number of around 50,000) with both the cases of 7% and 12% fluctuations in wind velocity at a frequency of 0.5 Hz. In their investigation, fluctuation amplitude of ±30% did induce hysteresis in the unsteady Cp while ±10% amplitude did not. The unsteady k was found barely dropping below the optimum k value.

4.1. Experimental Analysis on small VAWT:
Number of researchers have done a significant work in the experimental analysis of vertical axis wind turbine. Some of them are tabulated in Table 2.

<table>
<thead>
<tr>
<th>Literature</th>
<th>Specifications of VAWT</th>
<th>Test Conditions</th>
<th>Outcomes/Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ali et al. [50]</td>
<td>--</td>
<td>Wind speed 30km/hr</td>
<td>• Overall it can be said that the best performance was achieved by the bare rotor for the centred position over the entire range of wind speeds.</td>
</tr>
<tr>
<td>Danao et al. [51]</td>
<td>wind tunnel length - 8.5 m, Turbine was based on three NACA0022 blades with chord c = 0.04 m each supported by arms based on NACA0026 profiles.</td>
<td>The wind speed was 7 m/s with number of around 50,000 with both 7% and 12% fluctuations in wind velocity at a frequency of 0.5 Hz.</td>
<td>• Unsteady free stream causes a drop of efficiency.</td>
</tr>
<tr>
<td>Damak et al. [52]</td>
<td>Aspect ratio 1.57</td>
<td>Reynold number 79,794 – 147,059.</td>
<td>• The helical Savonius rotor is sensitive to the Reynolds number. The overlap ratio of 0.242 is better than the overlap of 0.0.</td>
</tr>
<tr>
<td>Saha et al. [53]</td>
<td>Blade chord = 120 mm, blade Height =220mm</td>
<td>Wind Velocity range 6 – 12 m/s</td>
<td>• The twist angle at 15º gives optimum performance at low air speeds.</td>
</tr>
<tr>
<td>Mclaren et</td>
<td>H-type design Three straight 8 to 11 m/s</td>
<td></td>
<td>• Low blade speed ratio test cases were</td>
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</table>
al. [54] blades 3 m in length mounted at a radius of 1.4 m. The airfoil profile is a symmetric NACA 0015 with a chord length of 450 mm truncated at the trailing edge to a final length of 420 mm. 

Sheldahl et al. [55] Number of buckets, 2 and 3; Rotor height, 1 and 1.5 m; rotor diameter 1 m; bucket overlap, 0.0-0.1 m. Wind velocity, 7 and 14 m/s; Reynolds number/meter, 4.32 x 10^5 and 8.67 x 10^5

Singh et al. [56] 2-bladed rotor. Effective rotor radius =0.565 m. Twist angle=17° Root and tip pitch angle = 20° and 3° respectively. Rotor solidity=8.27% Airfoil section = AF300 throughout. Design freestream velocity =5 m/s. Design rotational speed =500 rpm. Tip speed ratio=6.6. Wind speed = 4–11 m/s

Wekesa et al. [57] Blade material - Galvanized iron sheets two stage Rotors 3 bladed each Height (H)= 0.70m Rotor diameter(D)= 0.70m Blade and end plate thickness= 0.001m Overlap ratio β= 0.15 Aspect ratio = 1.0 Wind velocity 8 m/s

Takao [58] Blade profile NACA4518(3bladed) Radius 300mm Height 700mm Chord length 100mm solidity σ 1.0 Wind speed - 8.5 m/s

Loganathan et al. [59] Three rotors with 24, 32 and 40 blades with blade diameter of 40 mm and blade height of 160 mm were constructed. Wind speed - 8.5 m/s

Yen and Ahmed [60] NACA 0020 profile wind turbine blade with chord length of 207.5 mm and span of 300 mm Wind velocity - 10 m/s

- Increasing Reynolds number and/or aspect ratio improves performance
- Peak power coefficient attained by the 2-bladed rotor design at 6 m/s wind speed was 0.29.
- Turbulence intensity had a dual influence on small wind turbines. The presence of a turbulent in flow increases the kinetic energy available to small wind turbines at low wind speeds.
- The self-starting capability of the vertical axis wind turbine was improved on introducing an external turbulent inflow.
- The effect of guide vane geometry on the performance was clarified in the study.
- Turbulence intensity has a significant impact on the power output of a Savonius type micro vertical axis wind turbine.
- Actuation was found to be effective in altering the development of the pressure distributions and lift hysteresis loops for very low blade speed ratios below 2.
4.2 Numerical analysis of small VAWT:
Beside experimental analysis, researches are done in the field of numerical analysis for VAWT. Jain and Abhishek [61] predicted and analyzed the aerodynamic performance of a Vertical Axis Wind Turbine (VAWT) with variable amplitude dynamic blade pitching. The parametric study related the performance of VAWT to rotor solidity, blade airfoil and pitch amplitude. It was found that the amplitude of sinusoidal blade pitching has to be varied with wind speed and tip speed ratio to maximize the power extracted from the turbine for wide range of wind speeds and tip speed ratios. It was also found that high pitch amplitudes work best for tip speed ratios below 0.5 and the pitch amplitude should be reduced to approximately 10 for tip speed ratios greater than 2.0.

Dragomirescu [62] presented the results of experiment by a numerical study on a wind turbine with a cross flow runner. The study was aimed for two purposes i.e. Assessing to what extent such a turbine could be efficient in low wind conditions and other to study for getting in insight of the flow around and through the turbine. The results obtained suggested that the turbine can be operated only in a relatively narrow range of tip speed ratios, the corresponding maximum tip speed ratio was found lower than 0.6. Howell et al. [63] manufactured a small model research VAWT and tested over a wide range of operating conditions. The straight turbine rotor blade, with an aspect ratio of 4:1 operated at relatively low tip speeds and its performance showed a clear dependence on the rotor blade surface finish. Below a critical Reynolds number (30,000), the performance was enhanced by having the surface of the turbine roughened, but above this Reynolds number the power coefficient was found degraded. The tests also showed that the two and three bladed rotor models can produce similar peaks in performance coefficient, but that the three bladed designs did so only at a much reduced TSR.

Kamoji et al. [64] studied in which tests on helical Savonius rotors were conducted in an open jet wind tunnel. The results indicated that all the helical Savonius rotors have positive coefficient of static torque at all the possible rotor angles. The helical rotors with shaft were found with lower coefficient of power than the helical rotors without shaft. Helical rotor without shaft at an overlap ratio of 0.0 and an aspect ratio of 0.88 was found to have almost the same $C_p$ when compared with the conventional Savonius rotor. Fig. 6 represents the schematic diagram of twisted savonius rotor.

Fig.6. [64]Savonius rotor with helical blades (90° twisted)

Mohamed et al. [65] Carried out an aerodynamic investigation on H-rotor vertical axis Darrieus turbine for 20 different types of airfoils (Symmetric and Non-symmetric) by the help of two-dimensional Computational Fluid Dynamics in order to make best use of output torque coefficient and output power coefficient (efficiency). The attainable k-ε turbulence model can be used for a quantitative and qualitative examination of the unsteady performance of the turbine. The CFD procedure adopted was found able to get considerably better airfoil than the conventional Darrieus turbine which leads to a relative increase of the power output coefficient by 26.83% corresponding to the S-1046 airfoil compared to the standard symmetric NACA airfoils. Svorcan et al. [66] studied to define the look and basic dimensions of a small-scale VAWT that could be used in urban environment or placed over the top of a building. After analysis it was found that $C_p_{max}$ achieves the value of around 0.45 for every considered airfoil which is very satisfactory, greater variations in obtained values of $C_p_{max}$ for symmetric airfoils are probably caused by greater differences in aerodynamic coefficients at different Reynolds number. Wong et al. [67] did a review in which they advocated the merits of flow augmentation devices implanted on VAWT with a yawing mechanism. Augmentation device include the stator, diffuser, guide vanes, shroud, plate, deflector, or duct with the basic theory of obtaining a higher mass flow rate for the wind flow by converging the wind flow from a bigger flow area into a smaller area. With the corresponding venturi effect, the wind velocity increases before interaction with the rotor blade and therefore creates a higher positive torque on the machine. Fig. 7 represents the picture of rotor with stator vanes. Ultimately the paper suggests that wind turbine performance is improved by concentrating the wind flow to increase the wind speed.
Loganathan et al. [68] had done an analysis to find the effect of sizing of a multi-bladed Savonius rotor on power output. Primarily, a base model of the micro wind turbine with 8, 16 and 24 blades with blade length of 160 mm and rotor diameter of 300 mm, 40 mm was designed and its power outputs were measured over a range of wind speeds using a wind tunnel. The outputs were compared with the modified design by making the diameter of the rotor the length and radius of the blades to double its previous magnitudes. Results showed that the average power output increased by about 80% when compared to the base model and double size for all 3 sets of blades (8, 16, 24 blades). It was also found that the power increased about 50% when the diameter of the blade was scaled up by double the size.

Almohammadi et al. [69] numerically investigated four methods, namely mesh refinement, Grid Convergence Index (GCI), General Richardson Extrapolation (GRE), and the fitting method, in order to get a mesh independent solution for a straight bladed vertical axis wind turbine power curve using computational fluid dynamics (CFD). The solution was produced by employing the 2D Unsteady Navier–Stokes equations (URANS) associated with two turbulence models (ReNormalized Groups (RNG) $\kappa$–$\varepsilon$ models and Transitional and Shear Stress Transport). The mesh independent power coefficient was produced using the General Richardson Extrapolation method found to be favoring. As an alternative, the fitting method showed a good potential for the predicting of the mesh free power coefficient without the need to consider a massive number of meshes. Mohamed [70] done a research with objective to improve the self-starting capability an H-rotor Darrieus turbine for wind energy conversion. For the corresponding purpose, the effect of the solidity and the effect of using the hybrid system between the drag and lift types of VAWTs were investigated in the paper numerically and experimentally. After validating the numerical procedure against the experimental measurements, accurate CFD simulations of the steady and unsteady flow around an H-rotor Darrieus turbine was carried out. It was found that the realizable ke 3 turbulence model can be used for a quantitative and qualitative analysis of the unsteady behavior of the turbine and the steady simulations can be used for calculating the static torque coefficients of different configurations. Chowdhury et al. [71] did a CFD analysis to analyze the viability of small scale VAWT on heighted buildings. After simulation in CFD with the turbine in both upright and tilted conditions they found that the numerical simulation data and experimental data were in good accord with each other.

Chong et al. [72] had done a theoretical study to design a power augmented guide vane (PAGV) for a vertical axis wind turbine i.e. Sistan Rotor. The developed PAGV was found to increase the rotational speed of Sistan Rotor 1.75 times whereas the rotor torque and power output was found to increase by 2.88 times and 5 times respectively. The power augmented guide vane is a device which works on the principle of guided flow. In case a fluid flows is guided fashion then the energy lost by it could be lower rather than that of an unguided flow. The PAGV consist of a guiding mechanism which corrects the angle of wind before facing the blades of Sistan rotor. This improves the efficiency of the rotor to a significant extent which could be clearly understood by rotational speed of wind turbine rotor verses time (with presence of PAGV).

5. Conclusions:

Nevertheless utility scale wind turbines are serving to harness the wind energy but Small scale wind turbines can serve a better option for harnessing wind energy due to they are cost effective, easy to manufacture, portable safe and environmental friendly. World is in gesture of switching toward the green energy resources for fulfilling its power needs and research in the field of SWT is one of the milestone in wind energy generation. After going through required number of papers thoroughly the following substantial conclusions can be drawn

- It is observed that unitary scale wind turbine has its impact on the climate of world but it is not clear that the impact on environment due to large scale wind turbine is directly connected or just a correlation.
- Lot many things are happening in the field of SWT globally however there is no concrete definition for categorization of small scale wind turbine. By
differentiating the small scale and large scale wind turbines, it would be easier to enhance the development of SWT and appreciating public use of it (Could be by government aided programs and providing subsidies).

- Many Researches are done worldwide to prove that SWT has a huge potential for energy generation via renewable energy source.
- Most of the researches has happened between the variables associated with the corresponding performance parameters e.g. \(C_p\), Rotor diameter, chord length other geometries etc.
- The commonly used wind turbines are HWAT. The VWAT are used very little in societies however ample researches are happening associated with VWAT. The use of VWAT is not as much as HWAT. Twisted rotor Savonius windmill are at research level however they show smooth power production capability.
- Naturally available materials can be directly used for corresponding components for SWT e.g. bamboo sticks can be used for making the tubular tower of SWT however not much research has happened in this connection.
- Not much research is done for harnessing the power from wind turbine at low speed of wind i.e. 5m/s or less. Harnessing energy by low wind speed could prove a boon in the field of SWT as most of the parts of earth have very low wind speed similarly the wind turbines are not very suitable for the areas where the turbulence of the wind is very high. Turbulent wind also contains energy with it, the research in field of excavating energy from highly turbulent wind without damaging the wind turbine can also prove betterment in the corresponding field.
- No researcher has been worked integrated small scale wind turbine. There is research potential of working on performance analysis on integrated small scale wind turbine as compared to unitary same capacity USWT.
- Very few research studies are available in reported literature which has worked with low wind speeds (less than 4 m/s). There is research potential on working with developing and performance analysis of SWT working with wind velocity less than 4 m/s.

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