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Design Aspects of Small Scale Wind Turbines: A Review

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Abstract: The limited nature of fossil fuels is an important incentive for global transition towards renewable energies. One of the viable sustainable energy sources is wind. The large-scale wind farms are not a good option due to their undesirable effects on environment; hence installation of small scale wind turbines (decentralized grid system) is a sustainable option. This paper presents review on design of different types (i.e., horizontal axis and vertical axis) of small scale wind turbines. The blade design, control, aerofoil and aero-acoustic aspects of small scale wind turbines were reviewed.

Keywords: Small scalewindturbines, Blade design, Aeroacoustics, Aerofoil

Introduction:

Nowadays the world is facing problem due to energy crises, 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. Wind energy is a promising technology which can contribute to reduce of carbon credit and reducing the polluting factors accumulated due to use of fossil fuels. In wind turbines the kinetic energy of wind is used to develop rotational power over the shaft.According to world wind energy association, the worldwide wind energy capacity extended to 486661 MW by the year of 2016, out of which 54846 MW were installed in 2016. This represents the growth rate of 11.8 % whereas in 2015 it was 17.2%.Approx 5% of totalworld electricity demand is full filled by the wind power.Latin America and China has increased their share of new wind power project installations to 6.5 % and 5.3 % respectively.

The general technique in the field of wind energy harnessing is the use of unitary big capacity utility scale wind turbine. The utility scale wind turbines are deployed to supply power to large number of consumers by a single unit.The utility scale wind turbine is a centralized large sized wind turbine which requires a huge amount of financial investment and organizational set up. In contrast regarding the case of utility scale wind turbines some researchers have found the negative outcomes over climate.

Wang etal. (2010)found by his exhaustive review that deploying large scale wind turbine to get 15-25% power demand of world it can lead to increment of 1^0C of ambient temperature.Similarly, Fiedler et-al (2011) did a survey 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. Small scale wind turbines which are with capacity ranges of 1 kW 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 is required. Small scale wind turbine can be implanted over the roof top of building and the supervision required for that purpose is not of that much degree as compared to utility scale wind turbine.

In 2015, a cumulative total of at least 990000 small wind turbines were installed all over the world. This is an increase of 5% compared with the previous year, when 945000 units were registered. It means that worldwide several million families are getting power from small scale wind turbine. However only in Italy the number of new installations increased during 2015. The recorded small-scale wind capacity installed worldwide has reached more than 945 MW as of the end of 2015. This is a growth of 14 % compared with 2014, when 830 MW were registered. According to World wind energy association, China accounts for 43 %, the USA for 25 %, UK for 15 %, and Italy for 6.3% of the global capacity.

Small scale wind turbines are gaining their importance around the globe. In July 2012, a new kind of feed-in tariff was approved by Japan in order to boost the country's production of wind and solar energy production. Small scale wind power turbines soon will be subsidized at least 57.75 JPY (about 0.74 USD /kWh). In UK, the people in rural or suburban parts of the UK can select for a wind turbine accompanied with an inverter to supplement local grid power. The UK's Micro-Generation Certification Scheme (MCS) has a provision of feed-in tariffs to owners of qualified small wind turbines. The owners can now install a micro renewable energy system and shall be getting paid for that (Bahaj et al., 2006).

Small scale wind turbines are also handy in some autonomous applications which require a very high level of reliability. Some units are designed very light weight in their structure, e.g. 16 kilograms, 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. These wind turbines can be used as are liable source of energy when they are sized properly and are used at their optimum conditions. This paper presents a literature review on general classification and design aspects (blade design, control, aerofoil and aero-acoustic) of small scale wind turbines.

2. Small Scale Wind Turbines:

There is no fix threshold limit in regards of any feature of wind turbine to separate the utility scale wind turbine from a small-scale wind turbine.However, the small wind turbines rotor is usually of 1.5 to 3.5 meters in diameter which can produce 1-

10 kW of electricity at their optimal wind speed (Tummala et al., 2016). Fig. 3 shows the classification of wind turbines based on rotor diameter.Table 1 demonstrates the

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classification of wind turbines based on power rating and applications.

Small scale wind turbines mainly can be classified based on the axis of rotation i.e., vertical and horizontal.

Vertical Axis Wind Turbines (VAWT):

Vertical axis wind turbines are those whose rotor axis is in vertical direction. These turbines do not have any yawing mechanism or self-starting capability. The generator location for these turbines is on ground and their height of operation is very low, hence making them easier for maintenance. The ideal efficiency for these turbines is more than70%. The vertical axis wind turbines are classified into two major types:

(i) *Darrieus Wind Turbine:* The Darrieus wind turbine is a type of vertical axis wind turbine which consists of a number of straight or curved blades mounted on a vertical framework. These turbines work from the lift forces produced during rotation.

(ii) *Savonius Wind Turbine:*Savonius wind turbines are drag based wind turbines consisting of two to three scoops. These turbines have an ‘S’ shaped cross section when looked from above. As they move along the wind, they experience lesser drag and this difference in drag helps these turbines to spin. Due to the drag, the efficiency of these turbines is less when compared to other types of turbines.

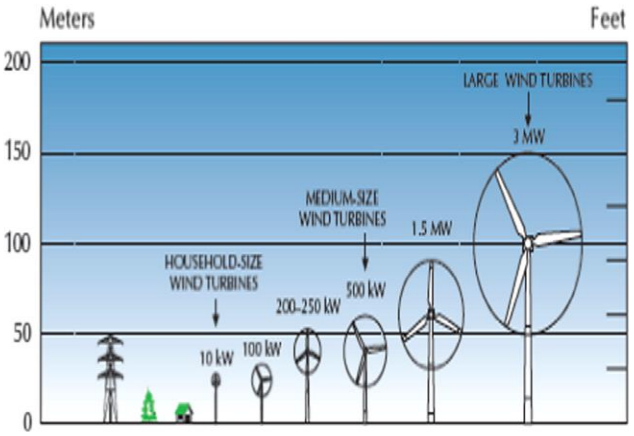

Fig. 1: Classification of wind turbine according to capacity (Tummala et al., 2016)

Table 1: Wind turbine classification based on power rating and applications.

Scale	Power rating	Rotor diameter	Application
Micro	50W to 2 kW	Less than 3 m	Remote
Small	2 kW to 40 kW	3 m to 12 m	Homes and farms
Medium	40 kW to 999 kW	12 m to 45 m	Village power, Hybrid system
Large	More than 1 MW	46 m and larger	Central station wind farms

Horizontal Axis Wind Turbines (HAWT):

Turbines whose rotor axis is in the horizontal direction are called as horizontal axis wind turbines. Unlike vertical axis wind turbines, horizontal axis wind turbines have the ability to self-start and yaw. These turbines are highly dependent on wind direction and hence they are generally operated at higher heights than the VAWT. The ideal efficiency for these turbines is between 50% and 60%.

Today most of small wind turbines are found to be traditional horizontal axis wind turbine, however vertical axis wind turbines are also a growing type of wind turbine in the small scale wind market. Nevertheless, some small wind turbines are designed to work at low wind speeds, but in general small wind turbines require a minimum wind speed of 4m/s for better performance.

3. Effects of Design Parameters on Performance of Small Scale Wind Turbines:

In Small scale HAWT, much emphasis was given on the factors such as tip speed ratio, rotor speed and pitch angle for a specific aerofoil which affect the performance of wind turbine. There is a big research potential of wind direction effect, wind turbulence intensity and wind gust. It was also reported that variable pitch with VAWT would result with higher power coefficient.

A 3-bladed turbine of rotor diameter 2.1 m wastestedina wind tunnel upto a wind speed of 13m/s.At various wind speeds, thev alueso ftip speed ratio(TSR)variedfrom2to 8 andthemaximum Coefficient of performance (Cp) of 0.2occurredat TSR6. It was also observed that at a particular wind speed, the maximum power value decreased with the increase in yaw angle (Freere et al., 2010).

Singh et al. (2013) observed that the rotor touched the Cp values up to 0.l, 0.217 and 0.255 with the wind speeds of 4, 5 and 6 m/s respectively whereas the baseline 3-bladed rotor targeted 0.052, 0.112 and 0.15 at these wind speeds as shown in Fig. 2.Thisshowsthatthetwobladedrotorshave abetter Cp in thelowwindspeedrangeof3 to 7 m/s.Attheoptimumpitch(β=18°), thetwo-bladedrotorproducedmorethandoublepower than thebaselinerotor.Onlyatthepitchangleof15° and atawind speed of4m/s,thepoweroutputofthebaselinerotorcoincided with thatofthetwo-bladedrotor.

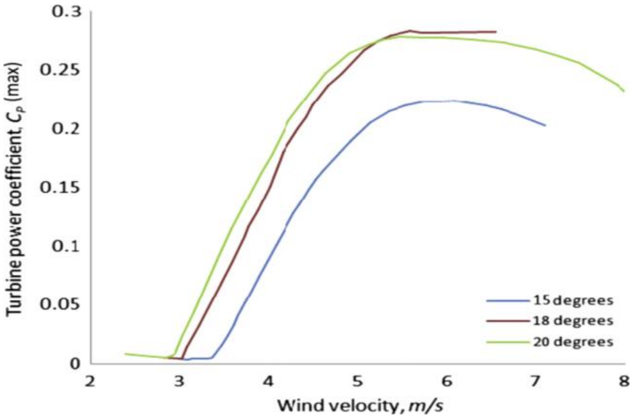

Fig. 2: Minimum power coefficient of the turbine as afunction of wind velocity at different pitch angle (Singh et al.,2013)

Design and characterization were studied of a small-scale wind energy portable turbine (SWEPT), of 39.4 cm rotor diameter operating below the wind speed of 5 m/s by Kishore et al, (2013). Maximum coefficient of performance of 14% was obtained at optimal tip speed of 2.9m/s. It had low cut in wind speedof2.7m/sandwhichgave0.83Wofelectricpowerattherated windspeed of 5m/s. It was also observedthatthediffuser-augmentedSWEPToflength approximatelythesameastheturbine'sdiametercouldproduce 1.4–1.6timeshigherpoweroutputthanaSWEPTwithoutdiffuser. A verysmallscale,4-bladedwindturbine have arotordiameter is 500mm, and havingNACA2404airfoilprofile was studied by Hirahara et al. (2005). Theresults showed thattheturbinehasagoodefficiency inwind speed rangeof8–12m/swithnetefficiency and powercoefficient as0.25and0.36respectively.It also showsgood performance atlowertipspeedratios.Themaximumpower coefficient wasabout0.40whenthetipspeedratiowas2.7.

Duquette et al. (2003) had conducted a numerical study and found that increase in power coefficients at lower tip speed ratios was observed with increase in the solidity. Also, the power coefficients increased with the increase in the blade number at a given solidity as shown in Fig. 3. An increase in the solidity from the conventional 5–7% to a range of 15–25% yielded higher Cp values while lowering tip speed ratio at maximum Cp to 2–4. Due to lower tip speed ratios reduce structural requirements, blade erosion and noise levels.

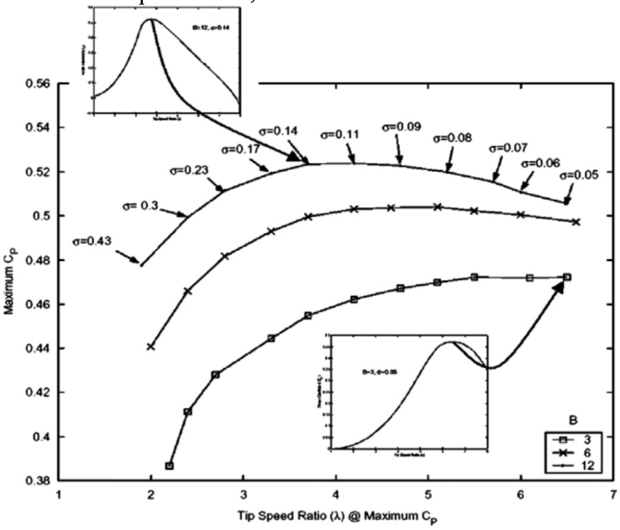

Fig. 3: Optimum design maximum Cp versus tip-speed ratio for various blade numbers (By Blade element momentum theory analysis) (Duquette et al., 2003)

A study on small scale HAWT having NACA4415 profile blades was carried out in order to investigate the effects of tunnel blockage on the power coefficient in wind tunnel tests by Chen and Liou (2011). The blockage factor (BF) was determined by measuring the velocities at different points in the wind tunnel and the studies were carried out on a 6-bladed turbine. It was observed that the blockage effects increase as TSR and BF increase, and β decreases. A Relationships between Cp and TSR under six different β for 12 blades, were plotted as shown in Fig. 4 found that smaller the β value, larger the Cpmax. The tunnel blockage effect was small for small TSR, and BF approaches a constant value at a certain TSR, at which point the blades act like a solid wall. It was observed that the tunnel blockage effect and the decay rate of BF are larger for the 12-blade turbine than the 6-blade for the same TSR. It was also determined that no blockage correction is necessary for β=25°, and the blockage correction is less than 5% for BR less than 10% and for TSR less than 1.5.

A small HAWT studied by Mayer et al. (2001)and reported that for a pitch angle of 0°, there is a longer idling period due to the very high angle of attack and the idling period decreased with the increase in blade pitch angle. It was seen that at the pitch angle of 20°, shortest start was obtained.

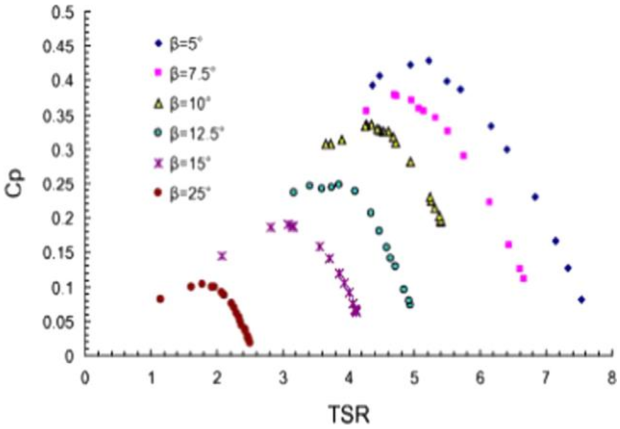

Fig. 4: Relationships between Cp and TSR under six different β for 12 blades, at U=8 m/s and BR=28.3 % (Chen and Liou, 2011)

The AF 300 airfoil was associated with 8 other airfoils designed for low Reynolds application for small horizontal axis wind turbines was studied by Singh et al. (2012).They plotted L/D ratio, CL values at different angles of attack for those 8 airfoils with AF300 as shown in Fig. 5.

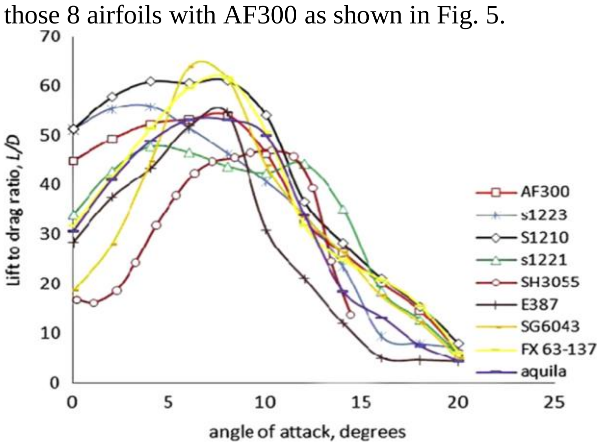

Fig.5: L/D ratio, CL values at different angles of attack plotted for 8 different blades (Singh et al., 2012)

For different angles of attack, the forces of lift and drag were calculated and pressure distributions over the surface of the airfoil were obtained. The maximum lift coefficients were obtained at the stall angle of 14°. Flow visualization showed that flow stayed fully attached to the airfoil surface from Re as low as 56,000 at an angle of attack 8° and maintained a fully attached flow up to 14° angle of attack for Re as low as 75,000.

A small wind turbine blade using the blade element momentum (BEM) method for a three bladed, Bergey XL 1.0 turbine, with 2.5 m diameter rotor, up wind orientation, rated power of 1000 W at 11m/s wind speed and tip speed ratio of 5.85 and SD 7062 airfoil was made by Song et al. (2014). Blade was tested at the original designed pitch angle and also at 5° and 9° pitch angles. The new blades showed better aero dynamic performance in high speed wind conditions but under low wind speeds, the original blades showed better performance. The original blade was predicted to have higher Cp than the new blades at designed pitch (0°) and tip speed

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ratio λ less than 4.5, whereas at higher λ the new blades were predicted to have higher Cp values as shown in Fig. 6.

The new blades at 5° pitch produced the highest power at wind speeds over 9 m/s, while the new blades at 9° pitch produced less power over all, but performed best at low wind speeds.

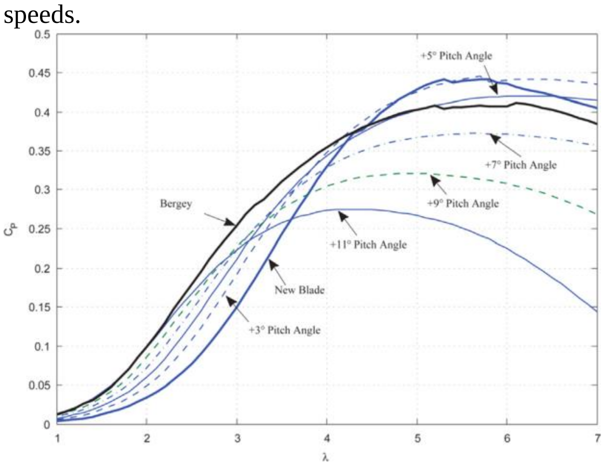

Fig. 6: BEM predictions of power coefficient for the new blades at different overall pitch angles, compared to the original Bergey blades (Song et al., 2014)

4. 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 the reported literature, 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.
- The blade characteristic is a function of wind speed, yaw angle, with and without a nose cone. It also observed that at a particular wind speed, the maximum power value decreases with the increase in yaw angle. At various wind speeds, the values of TSR vary from 2 to 8 and the maximum Cp is 0.2 at a TSR 6.
- The BEM theory prediction is more accurate for large scale wind turbines than small scale due to Reynolds number and three dimensionality effects (Separation delay at the in-board sections radial flow and down wash effect).
- The two bladed rotors have a better Cp in the low wind speed range of 3 to 7 m/s. At the optimum pitch (β=18°), the two-bladed rotor produces more than double power than the base line rotor. Only at the pitch angle of 15° and at a wind speed of 4m/s, the power output of the base line rotor coincides with that of the two-bladed rotor. Maximum coefficient of performance is 14% obtained at optimal tip speed of 2.9m/s for wind tunnel.
- The turbine (rotor diameter is 500 mm and 4 bladed) has a good efficiency in wind speed range of 8–12 m/s with net efficiency and power coefficient as 0.25 and 0.36 respectively. It also shows good performance at lower tip speed ratios. The maximum power coefficient was about 0.40 attip speed ratio 2.7.
- An increase in the solidity from the conventional 5–7% to a range of 15–25% yielded higher maximum Cp values while lowering tip speed ratio at maximum Cp to 2–4.

References:

i. *Chen TY, Liou LR. (2011) Blockage corrections in wind tunnel tests of small horizontal-axis wind turbines. ExpTherm Fluid Sc; 35(3):565–9.*

ii. *Duquette M.M andVisser KD (2003) , 'Numerical Implications of solidity and blade number on rotor performance of horizontal scale wind turbines', Transactions of the ASME , Vol. 125*

iii. *Fiedler BH and Bukovsky MS (2011), 'The effect of a giant wind farm on precipitation in a regional climate model', Environmental Research Letters, Vol.6, No.4.*

iv. *Freere P, Sacher M, Derricott J, Hanson B. A low cost wind turbine and blade performance. Wind Eng2010; 34(3):289–302.*

v. *Hirahara. H, Hossain MZ, Kawahashi M, Nonomura Y (2005), 'Testing and performance of very small wind turbine', Renewable energy, Vol.30 pp. 1279-1297*

vi. *Kishore R.A, Coudron T, Priya S (2013), 'Small Scale Wind Energy Portable turbine (SWEPT)', Journal of wind energy and industrial aerodynamics, Vol.116, pp 23-31.*

vii. *Mayer C, Bechly ME, Hampsey M, Wood DH. (2001) The starting behavior of a small horizontal-axis windturbine.RenewEnergy; 22(1):411–7.*

viii. *Singh RK, Ahmed MR (2013) , 'Blade design and performance testing of a small wind turbine rotor for low wind speed applications', Renewable Energy, Vol.50 pp 812-819.*

ix. *Singh RK, Ahmed MR, Zullah MA, Lee Y-H. (2012) Design of alow Reynolds number airfoil for small horizontal axis wind turbines. RenewEnergy; 42:66–76.*

x. *Song Qiyue, Lubitz William David. (2014) Design and testing of a new small wind turbine blade. J Sol Energy Eng; 136(3):034502.*

xi. *Tummala A, Velamati R.K, Sinha D.K, Indraja V, HariKrishna V (2016), 'A review on small scale wind turbines',Renewable and Sustainable Energy Reviews, Vol.56 pp. 1351-1371.*

xii. *Wang C and Prinn RG (2010), 'Potential climatic impacts and reliability of very large-scale wind farms', 'Atmospheric Chemistry and physics'Vol.10, No.4.*