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A Review on Small Horizontal Axis Wind Turbine

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Abstract: *With over exploitation of rapid depletion of fossil fuels and the increasing need for the use of non-renewable resources for fuel, Wind energy has been one of the most accepted source of new electricity generation and holds a major share in the renewable market. There has been extensive research done on large wind turbines and numerous onshore and offshore wind farms installed across the world. Along with the large turbines, the work on small turbines has also been considerable. This paper reviews the small wind turbine in terms of its performance, the material and on the aerodynamics of blade profiles.*

I. Introduction

The over exploitation of fossil fuels owing to increasing population and rapid industrialization has led to drastic effect on the earth's atmosphere leading to ozone layer depletion, increasing carbon dioxide footprints, increasing average temperature of surface and that of ocean. This has led to the research of renewable sources of energy which are abundant in nature. The winds which are caused due uneven heating of earth are one of the prominent sources for power generation. Wind turbines in large clusters forming a wind farm capture the kinetic energy of the winds which is converted to machinal energy which rotates shaft of a generator to produce energy. India has a target of 60 GW energy production by 2022. The wind energy is catching up momentum and there is a potential of 10 – 12 GW growth for next 3 years before the start of 2018 financial year as reported by Ministry of New and Renewable Energy (MNRE) [19].

Early wind turbines were used to extract water and grind grains. The modern wind turbines are used for large scale power generation. The research is continuously carried out so that the efficiency reaches close to the Betz's limit of 0.592. The research has been considerablylessfor small wind turbines generating few Kilowatts of energy to power buildings, homes and small commercial establishments. The small wind turbines can be installed at rooftops or close to the site. Rural areas facing scarcity of power greatly benefit from small wind turbines as they can be easily installed and transported.

The paper reviews the characteristics of small wind turbine. Section 1 introduces the small wind turbines followed by the review of its performance in terms of stress and deformation. The materials are followed later and then the aerodynamics of blade profile.

II. Small Wind Turbine

The power generated by wind turbines varies from a few watts to megawatts depending on the rotor size, wind velocity, tower height etc. Turbines are classified as small or large wind turbines based on the power generated by the wind turbine. IEC 61400-2 safety standard for small wind turbines defines a small wind turbine as having a rotor size less than $200m^2$ which correspond to power less than 50 KW. This limits the rotor radius to 8m, most small turbines though have diameters starting from 1m. The power generated by the turbine is directly proportional to the square of rotor diameter and to the third power of wind velocity. Small Wind Turbines are broadly classified by their axis of rotation as Horizontal axis wind turbine and Vertical Axis wind turbine.

III. Horizontal Axis Small Wind Turbine.

The Horizontal wind turbines have the main rotor and the electrical generator are placed at the top of the tower. Large wind turbines are guided by sensors to face the wind while the small turbines have a wind vane. The work done in small Horizontal Wind Axis Turbine has been presented in the following sections

a. Performance

This section discusses the static performance of small wind turbines blades in terms of stress, deformation and natural frequencies.

Kale et al. [1] worked on static behaviour of glass fibre reinforced plastic blade of new blade profiles IND 15045 and IND 09848 and observed maximum deformation without being deformed plastically is at the tip, indicating good elastic properties for design speed of 40m/s. Equivalent load by CFD simulation was found 2KN at 1m from root. Maximum stress was around 150 MPa experimentally and simulation showed lesser stress than experimental values.

Kale et al. [2] carried out vibration analysis on a 600mm long blade of NACA 4412 profile madeof glass fibre reinforced plastic with and without steel mesh. The results showed a 2-3% increase in natural frequencies of the first three modes for the blade with steel wire mesh.

Amer et al. [3] compared deformation and natural frequency for 0^o and 90^o orientation glass fibre blade of NACA 23014 profile of length 5m. Significant decrease in natural frequency was observed for 90^o orientation when compared to frequency obtained experimentally for both the cases. 0^o orientation showed little increase in frequency when prior modal analysis. 90^oorientation gives less deformation than 0^o orientation.

Mouhsine et at. [4] analysed a 43.2 m long E- glass fibre blade of S818; S825, S826 profiles at the root, the blade body and tip respectively. Blade element momentum determined the blade design. A maximum deflection of 0.045 m was observed at a wind speed of 12 m/s for tip speed ratio of 8.

Kumar et al. [5] performed vibrational fatigue analysis on a blade of NACA 63215 profile made of Kevlar, Glass Fibre Reinforced Plastic (GFRP) and Carbon Fibre Reinforced Plastic (CFRP) materials. Lower density composites such as Kevlar, CFRP have higher natural frequencies, pre-stressed vibrations and bigger deflection. The GFRP had low natural frequencies, pre-stressed vibrations, lesser deflection because of its mechanical properties.

Kong et al. [6] investigated a 750 KW E-Glass epoxy blade spanning 23.2m with a maximum chord of 2.1 m and tip chord 0.5 m of NACA 63-218 profile. GL regulations along with IEC61400-1 international specification was used to determine the load cases. 4 load cases were applied, at rated speed of 12.5 m/s, rated speed plus gust at 9 m/s, cut out speed of 25 m/s plus extreme wind speed condition and case 4 was gust at 55m/s. The measured deflection for last load case was 1978.2 while the predicted value was 1921 mm resulting in acceptable error of 3 %.

Cox et al. [7] designed a 70 m long blade of carbon and glass plies of 0^o, $+45^o$, -45^o for extreme operating gust (EOG) and Extreme Wind Model (EWM) conditions. Material strains, deflections, critical buckling were the failure criteria. Largest deflection and strain were found In EOG case, while the EWM was most severe in critical buckling load, as it had larger load then the EOG case. Blades were tested for four positions namely pointing down, horizontal-rotating upwards, pointing up, horizontal-rotating downwards. Maximum deflection was 5.12 m for EOG case for pointing up direction.

b. Materials

Proper choice of materials plays a vital role in blade design. Material should be such that the blades are light and at the same time meet the structural requirements. Early wind turbines were manufactured using wood as it was readily available and cheap. Wood was later replaced by steel owing to it poor strength. Aluminium then replaced steel as the steel blades were heavy. Aluminium had problems of fatigue resistance and high cost. Modern wind turbines are made of composite materials. Composites have advantages of high strength to weight ratio, good corrosion resistance, long life, etc. Fibres commonly used are glass and carbon fibres with epoxy resins. Natural fibres are now being considered as a suitable material because of its desired properties like low cost, high specific strength, bio- degradable, eco-friendly characteristics [10]. Small wind turbines, when compared to large turbine blades, can me made from wide range of materials. This section presents reviewon the wind turbine blade materials.

Maskepatil et al. [8] performed Analytic Hierarchy Process (AHP) on wood, glass fibre, carbon fibre, steel and Aluminium considering density, strength, corrosion, availability and cost. Priority value was highest for carbon fibre, its value being 0.2507. Glass fibre followed with a value of 0.2239. Steel and aluminium showed the same priority and wood showed the least priority.

Kale et al. [9] performed FEA on 3 specimens of outer surface made of glass fibre reinforced plastic (GFRP) with cores of low-density PVC foam, low density balsa wood, and a low-density fibre reinforced foam and one specimen with carbon and glass fibre reinforcement. The blade was 1500 mm long for a power of 1 KW. For the wind speed of 45 m/s carbon fibre showed least equivalent stress and deflection, while GFRP with low density fibre reinforced foam showed maximum cost saving and least weight.

Thomas et al. [10] reviewed the blade materials used and suggested the possibility of using natural fibres for experimentation and implementation Bamboo fulfils the material requirement for a turbine blade, and flax fibre passes the norms set by IEC61400. Carbon Nanotubes with naturals fibres show enhanced properties. Hybrid carbon glass fibres shows positive behaviour under static and dynamic loads.

Ahmad et al. [11] talk about the commonly used fibres and resins and performed a statistical FEA according to IEC-61400-1 standard on carbon fibre blade. Maximum deflection was found at tip which was 1.136 m and maximum stress on the blade was 6000Kpascal.Fibres most commonly used are carbon, glass, Aramid with matrix of polyester resin, epoxy resins, vinyl ester resins. Carbon fibres proved highest strength while glass fibres are cheapest. Epoxy is preferred over polyester resins for its good fatigue life and adhesion. Polyester resin has been tested to have health effects while working with it.

c. Aerodynamics

The turbine blades are the part of wind turbine that converts kinetic energy of the blade to mechanical energy and further into electricity by means of a generator. The conversion is limited by the Betz limit. To achieve values closer to Betz limit aerodynamics characteristics of the blade plays a major and hence design of blade profile is very critical. Factors that affect the performance of the chord and twist distributions, chord thickness. Lift and drag forces are dependent on the angle of attack and profile geometry. The lift forces must be high as they are to rotate the blade while drag is undesirable, but it cannot be avoided.

Blade Element Momentum (BEM) theory, is used to outline a procedure for the aerodynamic design and performance analysis of a wind turbine rotor. The blade must be designed considering its strength, aerodynamics and performance aspects. The design parameters to be considered are tip speed ratios, wind speed, angle of attack, power coefficient, thrust coefficients. The following section discusses the characteristics and aerodynamics of turbine blade profile.

Kale et al. [12] carried out optimization of 600 mm, 600 W, NACA 4412 profile blade considering enhancement of power performance and low speed starting behaviour by developing MATLAB program. Thickness and chord reduced after the optimization. Power coefficient reduced initially near the hub, but there was a significant increase towards the tip of the blade. No significant change was observed in twist angle for optimized blade.

Birajdar et al. [13] presents the effect of design parameters such as the tip speed ratio, angle of attack, wind speed, solidity, number of blades, etc. on the aerodynamic performance of small WT and proposes the optimum values of these parameters for the newly designed blade profiles IND 15045 and IND 09848.The 1.5 m,1KW blade was optimizedandmaximum power coefficient obtained for the newdesigned blade was 0.5, at the tip speed ratio of seven. Theoptimum value of angle of attack is 4.5 degrees at the designedwind speed of 8.4 m/s.

Wang et al. [14] Compared an optimized blade for chord and twist angle with preliminary blade by Schmitz rotor blade design. Criteria for optimization was highest annual energy production (AEP) based on wind speed Rayleigh distribution. The blade was S809 profile and turbine was fixed-pitch variable-speed (FPVS). The optimized results showed no change in chord and a slight variation in twist angle. The AEP increased by 1.4 %. Power coefficient was higher for optimized blade.

Liu et al. [15] linearized the radial profiles of the blade chord and twist angles. Tip speed ratio varies with wind speed, the originally optimized chord and twist angle radial profiles for a preliminary blade design through optimum rotor theory would not necessarily provide the highest annual energy production (AEP). Heuristic approach for the blade design optimization through linearization of both the chord and twist angle radial profiles of the blade produced 3.33% higher annual energy production than its preliminary design version.

Vardar et al. [16] researched on various NACA profiles like, NACA 0012, NACA 4412, NACA 4415, and NACA 23012. strong correlation between rotor rotation rate and blade angle, between power coefficient and blade angle, and between power coefficient and rotor blade number. Increase in wind speed rate resulted in a higher correlation between rotor rotation rate and wind profiles, between rotor rotation rates and wind speed, between power coefficient and blade profiles, and between power coefficient and blade twisting.

Kale et al. [17] designed a new profile generating high lift coefficient and low drag coefficient. The designedairfoil had a maximum thickness of 12.93% of chord length at 27.40% of chord and camber of 4.76% of chord length at 47.10% of chord. Analysis was carried out up to wind speed of 12 m/s and Reynolds number Re = 500000, for angle of attack range 0° to 20°, for different tip speed ratio and air density 1.225 $kg/m^3$and kinematic viscosity of $1.647\times10^5 m^2/s$ was considered. From Computational and experimental results obtained it is concluded that experimental results are close to the values obtained from QBlade software. C_L /C_D ratio increases up to a maximum value and decreases gradually after a particular angle of attack. C_L /C_D ratio is much greater than that of existing airfoils considered for comparison.

Kale et al. [18] calculated the blade parameters for functioning of 1MW wind turbine E - glass fibre-reinforced plastic blade of NACA 63-621 and FX 66S-196 profiles by blade element momentum. Tip speed ratio selected was 7for rated speed of 12 m/s. The rotor blade diameter was 54m, with maximum chord of 2310 mm at r/R = 0.22, and ratio of thickness to chord being 35%.

IV. Conclusion

The paper reviews performance, materials and aerodynamic aspects of wind turbines. Small Wind Turbine offers great scope for generating useful power for rural and small power applications. Following can be concluded. Following can be concluded from the review.

- The structural aspects play a significant role in design of wind turbine. Maximum deflection should be limited in order to avoid breakage and to avoid the blade touching the tower. Stresses should be less than permissible limits. Stresses less than the limiting values provide scope for optimizing to reduce weight and cost.
- Appropriate choice of materials can reduce weight considerably. The research on materials must be extended to natural fibres as they have been tested to pass the norms and requirements for turbine blades.
- Aerodynamics plays a crucial role forthe performance of the rotor. The different profiles have different characteristics and must be selected wisely depending on the application to give maximum coefficient of performance.
- Proper positioning of blades ensures maximum power. Small Wind turbines generally do not have positioning system unlike Large Wind turbines and hence positioning of small wind turbines must be investigated.
- Most of the work has been done on parameters like tip speed ratio, chord, rotor speed for a specific airfoil. Not much work has been done in studying performance considering blade thickness, different spar positions,thickness of stars alone.

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