An Improved Design and Optimisation Procedure for Simplified Wind Turbine Rotors targeting Small-Scale Applications in Sri Lanka

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1. Introduction – A design procedure for optimized performance of simplified wind turbine rotors for small-scale applications is presented. The need for this research has arisen from the recent national initiative of the government of Sri Lanka titled ‘Battle for Wind Energy’ in promoting small scale grid connected wind plants for electricity customers under Net Metering scheme. Although the government envisages a wide spread dissemination of small-scale wind turbines, its success would be hindered by a number of issues. These include geographical mismatch between high resource sites and location of electricity consumers, lack of optimized wind turbine designs for low wind potential sites in the country, and limited opportunities for local manufacture. Therefore, the main objective of this research is to assist local developers to design optimum rotors for given electrical generators (as determined by customer requirements), suitable for wind characteristics at specific locations. Another objective is to enhance local manufacturing capabilities by providing a design option of a simplified rotor blade geometry.

2. Methodology – A study on the correlation between population density of electricity customers and wind energy potentials was carried out to categorize the demand centres based on wind energy potentials in proposing series of small-scale wind turbine designs. Accordingly, three wind potential regions were identified, namely low, medium and high with annual average wind speeds of 4 ms^{-1}, 5 ms^{-1}, 6 ms^{-1}.and rated powers were selected as 1 kW, 2 kW, 3 kW, respectively. The main steps of the proposed design procedure are (i) selection of design wind speed V_d based on local wind characteristics, (ii) selection of design tip speed ratio λ_d and number of blades B, (iii) selection of an electric generator based on the selected rated power requirement and (iv) the development of a mathematical model for the system characteristics based on the generator performance curves, rotor aerodynamics as determined by momentum theory, blade element theory, and other loss factors. The chord and blade angle variations of the rotor were obtained for the optimum performances under series of design conditions. A suitable rotor is then selected for each wind potential region based on optimum performance. These rotors were further simplified to have an optimum constant blade angle and chord length for easy manufacture.

3. Results and Discussion – Two blade configurations were selected for this analysis. One has λ_d= 4 and B = 4 (denoted by TSR4B4) while the other has λ_d = 5 and B = 3 (denoted by TSR5B3). A unique rotor design procedure was carried out to converge on a rotor radius R that would match λ_d with V_d. TSR4B4 design got R values of 1.12 m, 1.19 m, 1.30 m for the regions low, medium, high respectively and corresponding values for TSR5B3 are 1.26 m, 1.33 m, 1.46 m. The performance evaluation showed the dominance of TSR4B4 rotor design on low regions and TSR5B3 design on medium and high regions. The dominant rotor configurations were further simplified for constant chord and blade angle. Results show that all three configurations have an optimum constant blade angle of 7° and optimum constant chord lengths of 0.12 m, 0.13 m, 0.14 m respectively. The percentage decrements in energy conversion performance due to geometrical simplification are shown to be between 8-13%.

4. Conclusions – The new design procedure showed successful convergence on a unique blade diameter for each rotor configuration that allowed the λ_d to match V_d. The performance evaluation of rotor designs showed that high solidity rotors work better on the low wind region while low solidity rotors dominate medium and high wind regions. The performance reductions of simplified rotor designs are not significant and therefore would be an effective way to enhance local value addition.