DEVELOPMENT OF A SMALL WIND TURBINE ADOPTING FOLDED-PLATE BLADES -PERFORMANCE OF BLADES WITH ONE AND TWO STRAIGHT FOLDING LINES-

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Abstract

The authors have developed a simplified folded-plate blade with high power coefficient for small wind turbine on the design concept of the "Appropriate Technology (AT)".

In this study, the shapes of the blades are the tapered type, the straight type and the inversely tapered type and the diameter of all experimental model is 600[mm], the number of blades is 5, and the thickness of plate is 2[mm]. Each blade has a single folding line. The folding angles for these three types of the blades are 10, 20 and 30[deg] respectively. Blade pitch angles can be changed manually at 0, 5, 10 15, 20 and 25[deg]. In the experiment of all rotors, the wind speed in the wind tunnel is set at 10[m/s] and the torque and the corresponding rotational speed were measured gradually increasing the load. From the results of the experiment, the power coefficient Cp and the tip speed ratio λ were calculated to obtain the power characteristics for different blade types.

As a result, the maximum power coefficient for tapered type is Cpmax=0.278 when folded angle is 30[deg] and blade pitch angle is 10[deg]. For the straight type, Cpmax=0.303 when folded angle is 30[deg] and blade pitch angle is 15[deg]. And inversely tapered type is Cpmax=0.337 when folded angle is 30[deg] and blade pitch angle is 15[deg]. The most efficient model was inversely tapered type.

Additionally, for the inversely tapered type blades, we examined the performance of them with two straight folding lines whose angles are selected from 5, 10, 15 and 20[deg]. Blade pitch angles are also changed at 0, 5, 10, 15, 20 and 25[deg].

The result shows the maximum power coefficient is 0.372 when two folded lines whose angle are 5[deg], 10[deg] parallel the forward edge with blade pitch angle of 20[deg].

Key words: Curved plate blade, coefficient of power (Cp), tip speed ratio, bending and pitch angle, P.I.V. system

1.0 Introduction

The world population is expected to grow some 9 billion around the year 2050 (Yoshifumi *et al*., 2013). Such a rapid expansion of the population will bring increase in demand for food, water, energy and pollution of the environment. Therefore, a priority issue for 21st century is to assure enough energy and water in the developing countries needed for increasing agricultural output. Development of wind power equipments will be essential in achieving these power needs. This will require the use of appropriate technology to reduce cost and localize manufacture to developing countries because such technologies are perfectly applicable to the individual conditions of the people of a particular region. The main advantage of appropriate technology is that it emphasizes on; simple design using indigenous materials at low cost while operation and maintenance are practiced by local people (Yoshifumi *et al*., 2013).

Wind energy converters that have been built over the years can be divided into two categories: the lift machines and the drag machines. Some drag based machines such as the savonius rotor may achieve maximum power coefficient of greater that 0.2 and may have tip ratios greater that 1.0, this is primarily due to the lift developed when the rotor surfaces turn out f the wind as the rotor rotates (Wilson *et al*., 1976). The choice of the airfoil, chord length and the twist along the blade determine the performance of the blade. The approach to the choice of the airfoil, chord length and twist along the blade has changed over the years (Snel, 2002). When planning to generate electricity using wind turbine, combination of wind turbines and generators to use will depend on the wind conditions, topological conditions and the energy needs of the site. Furthermore, the technological level of the region, the available type of windmills or wind turbines, and even the practices and traditions of the local people could affect the design. Since power is directly proportional to the rotor area, large wind turbines have recently become so common. This however has had a consequence on the weight of the turbine and the overall cost which increases proportionately. Technological innovation is crucial in the development of low cost and smile size turbines while still maximizing on power capture The present work is focused on the use of the concept of "Appropriate Technology" to provide customized power needs to rural Africa. Appropriate Technology refers to a technology that is best fitted to the environment and conditions of the regional society and in answering the needs there (Yoshifumi *et al*., 2013). There is an increased interest in the study of the blade shape and curvature as a way of increasing energy capture without an increase in the turbine loads (Teresa *et al.* 2011).

The maximum rotor efficiency achievable is dependent on the propulsion methods. Drag method has widely been used although it has proved inefficient since the force and rotation of the rotor corresponds to the wind direction hence as the rotor speed increases, the relative velocity of the wind is reduced. Designs that are unshielded use the curved blade shapes which have a lower drag coefficient when returning into the wind. The curved blades shapes have the advantage of working in any wind direction (Peter and Richard 2012). The power coefficient of a turbine gives the ability of the turbine to capture the energy in the wind. Its value is dependent on the Tip Speed Ratio. The Cp and TSR can be calculated using the equations 1 and 2 respectively.

Power coefficient: $C_P = \frac{2\pi n / 60Q}{1/2\rho AV^3}$ (1) Tip speed ratio: $\lambda = \frac{2\pi Rn/60}{V}$ (2)

Where; C_P - Power coefficient, n - Rotational speed, ρ - Air density, V - Wind speed, A - Rotor area, R - Rotor radius, λ - Tip Speed Ratio, Q - Torque

The aerodynamic lift is an alternative method of propulsion which operates on the principle that the relative velocity at which air strikes the blade is a function of the blade velocity at the radius under consideration and approximately two thirds of the wind velocity. The relative airflow arrives at the blade with an angle of incidence (*β*) dependant on these velocities. The angle between the blade and the incidence angle is known as the angle of attack (α). (Peter and Richard 2012)

2.0 Methodology

2.1 Blade Design - One Straight Folding Line

Rotor diameter of experimental models is 600 mm and number of blade is five. Blade length of curved-plate is 270 mm; thickness is 2 mm using aluminum material. In this study, the authors prepared different type of tip length, root length and folded angle of blades. Blades pitch angle can be changed manually, confirmed by protractor and rod shown in Figure 2. To change the pitch angle and bending portion, defined names and symbols are designated as in Fig.1.

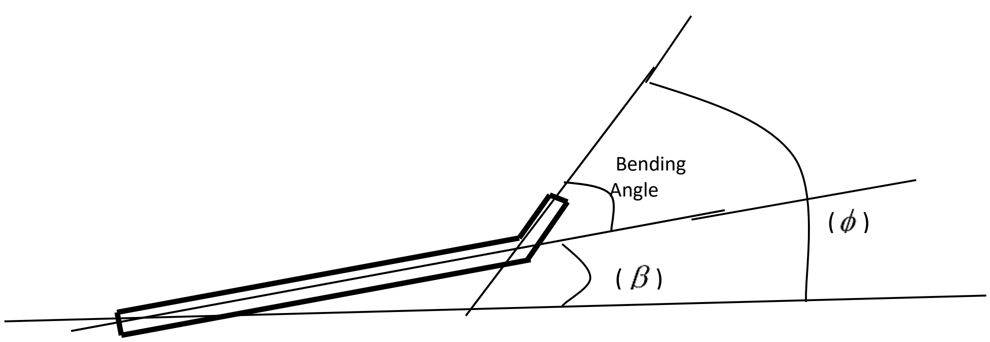

Figure 1: *A cross-sectional area showing the shape of the curved plates*

The 2-D designs for the straight type, tapered type and inversely tapered type curved plate blades at 10°, 20° and 30° folding angles were also designed and fabricated. Each of the types was curved at 10°, 30° and 30° on one side. Below is a cross sectional are of the blades when pitched at angle β and bent on one side at an angle. The plates in figures 2, 3, and 4 show the three types of blades that were fabricated. Each of the three types of blades were fabricated with bending angle of 10 deg, 20 deg, and 30 deg.

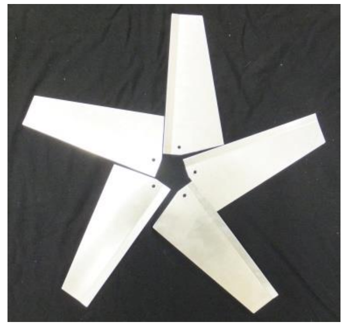

Figure 2: Tapered type aluminum curved blade

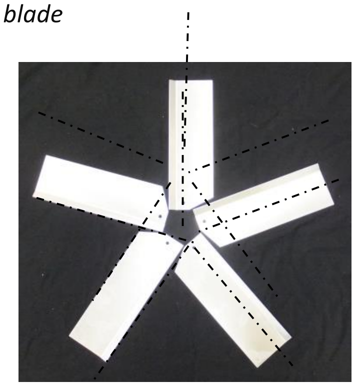

Figure 3: Straight type aluminum curved blade

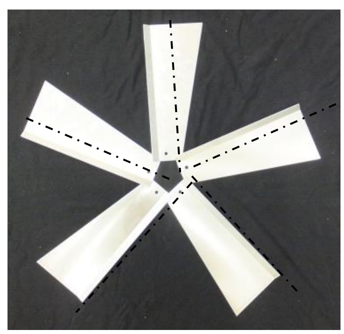

Figure 4: Inversely tapered type aluminum curved blade

2.2 Blade Design - Two Straight Folding Lines-

Additionally, for the inversely tapered type blades, we examined the performance of them with two straight folding lines whose angles are selected from 5, 10, 15 and 20[deg]. Blade pitch angles are also changed at 0, 5, 10, 15, 20 and 25[deg]. The plates in figures 5, 6, and7 show the three types of blades that were fabricated.

Figure 5: Type 1 of inversely tapered type aluminum curved blade

Figure 6: Type 2 of inversely tapered type aluminum curved blade

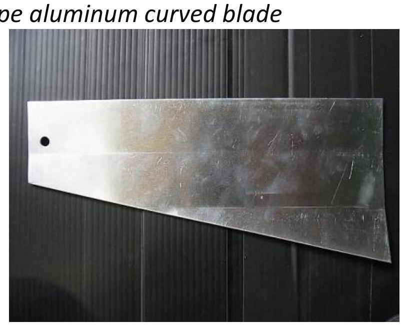

Figure 7: Type 3 of inversely tapered type aluminum curved blade

2.3 Wind Tunnel Testing of the Curved Blades

The wind tunnel used in the experiment is of the Effel type with an exit of 1.05m ×1.05m. The wind speed is adjustable between 2m/s and 20m/s.

An induction motor is employed as load in the experiment and the synchronized frequency is controlled by an inverter. For arbitrary determined frequencies, from high rotational speed for no load condition to lower rotational speed for gradually loaded condition, corresponding torque and rotational speed are measured by a torque converter and a revolution counter. Figure 8 shows the layout of the experimental apparatus while Figure 9 shows the turbine being tested in the wind tunnel.

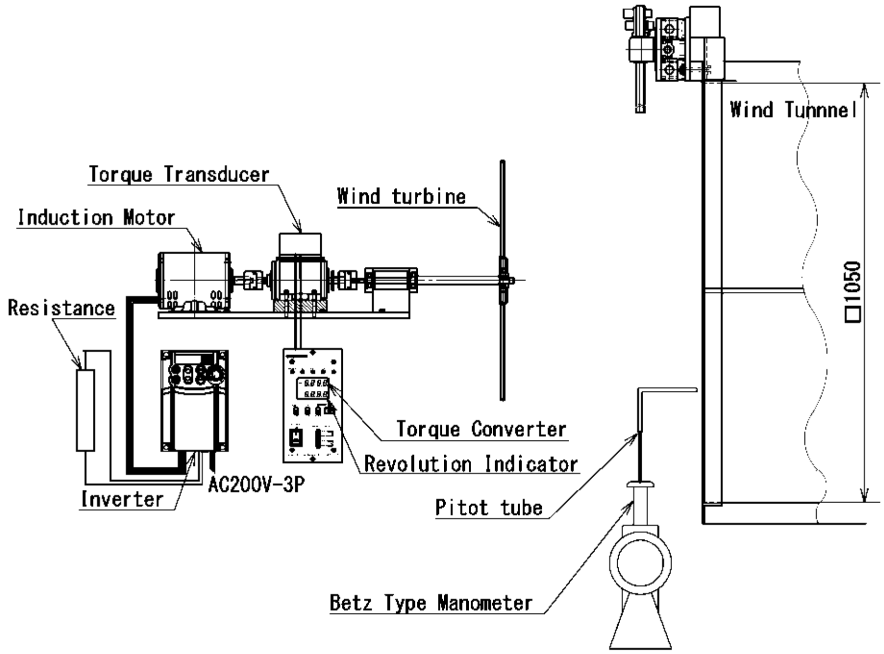

Figure 8: Schematic diagram of the wind tunnel setup

In the experiment of all rotors, the wind speed in the wind tunnel is set at 10 m/s and the torque corresponding to the revolution is measured by gradually increasing the load. From the results of the experiment and using equations 1 and 2, the power coefficient Cp and the tip speed ratio λ are calculated to obtain the power characteristics for different blade types.

Figure 9: Turbine undergoing torque testing in the wind tunnel

For the each of the blades curved blades, the tests were done 8m/s and 10m/s with the blades fixed at different pitch angles of 0, 5, 10, 15, 20 and 25 degrees. By the hand of angular adjustment for pitch angles is shown in Figure 10. The pitch angles were changed by turning the blades and measuring the angles using a protractor as shown in the figure below;

For each of the wind speeds the inverted frequency was increased to increase the rpm until there is no torque (ensuring that the 1300rpm limit is not exceeded.) The rpm was then reduced gradually while recording the corresponding torque after an interval of 50 rpm.

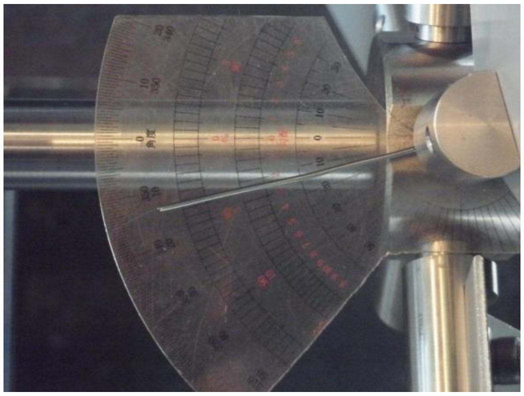

Figure 10: Mechanism of Angular adjustment

3.0 Results and Analysis

3.1 Wind Tunnel Testing of the One Straight Folding Line Blades

From the power curves in figure 11 to figure 19 shows that the at wind speed of 10 m/s the trend was the inverse tapered type giving highest Cps followed by the straight type and finally the tapered type. For the inverse tapered type at folding angles of 10°, 20° and 30° for the highest Cps were obtained at pitch angles of 15°, 10° and 15° respectively. This shows that the angles of attack that gave the best Cp for the inverse tapered type was 25°, 30° and 45°. At the same speed, the straight type gave the highest Cps at pitch angles of 15°, 15° and 15° for 10°, 20° and 30° folding angles respectively. This shows that for the straight type the angles of attack that gave the best Cps are 25°, 35° and 45° for 10°, 20° and 30° bending angles respectively. The tapered type gave the highest Cps at pitch angles of 20°, 15° and 10° for 10°, 20° and 30° folding angles respectively. This shows that for the tapered type the angles of attack that gave the best Cps are 30°, 35° and 40° for 10°, 20° and 30° folding angles respectively. At 10 m/s wind speed and considering the lowest Cp values obtained. All the blade types gave the lowest Cp value at 0o pitch angle for all the folding angles of 10°, 20° and 30° .

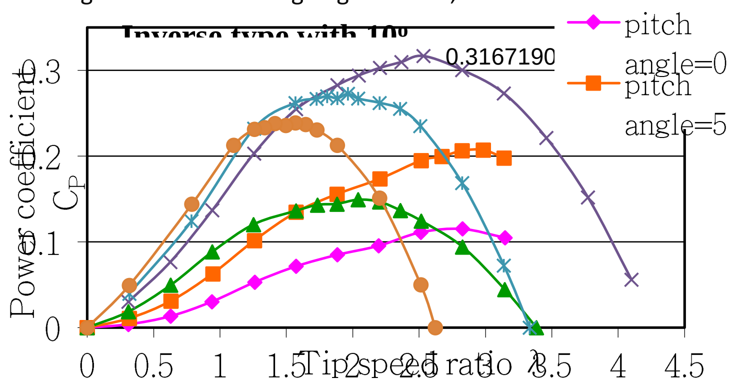

Figure 11: Power curve for inverse type at 10° folding angle and for 10 m/s

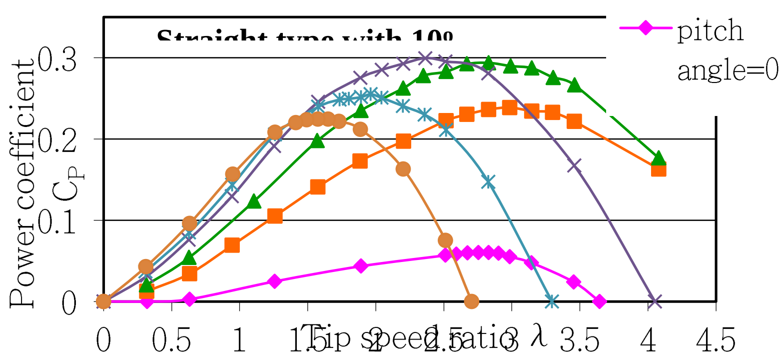

Figure 12: Power curve for straight type at 10° folding angle and for 10 m/s

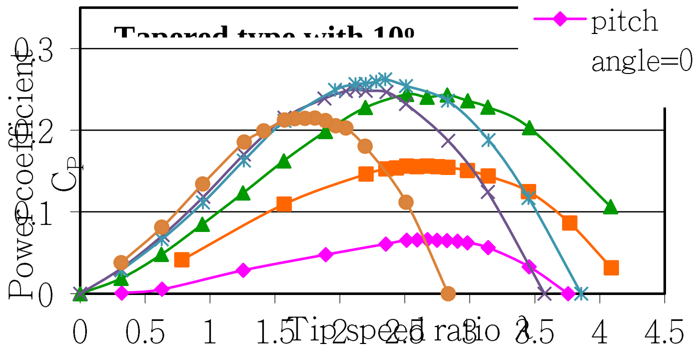

Figure 13: Power curve for tapered type at 10º folding angle and for 10 m/s

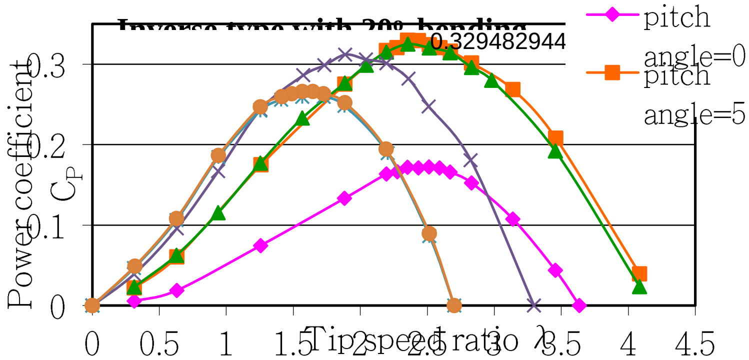

Figure 14: Power curve for inverse type at 20º folding angle and for 10 m/s

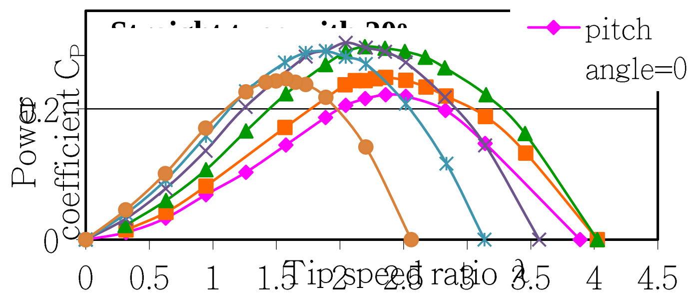

Figure 15: Power curve for straight type at 20º folding angle and for 10 m/s

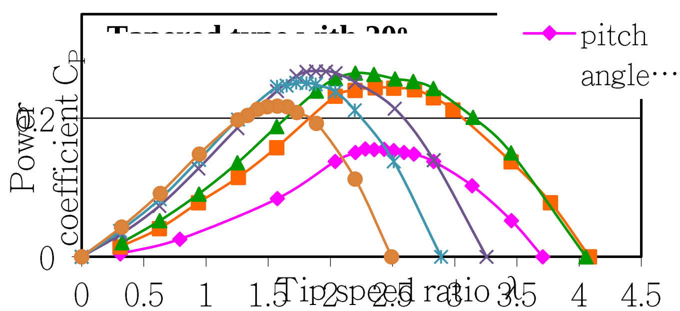

Figure 16: Power curve for tapered type at 20º folding angle and for 10 m/s

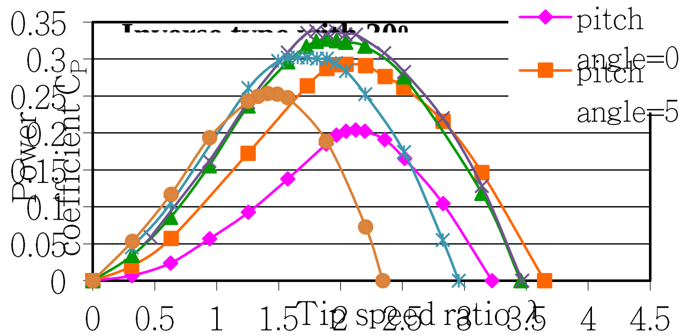

Figure 17: Power curve for inverse type at 30° folding angle and for 10 m/s

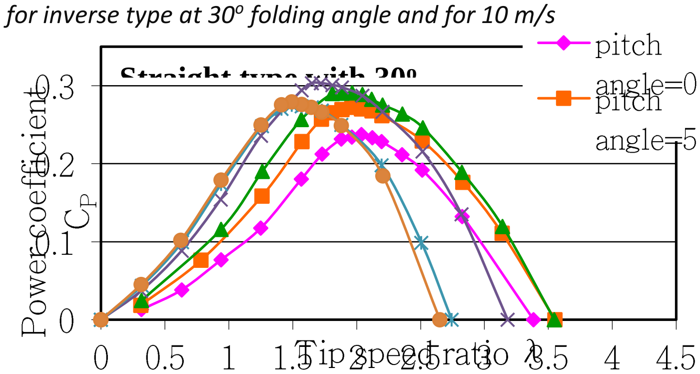

Figure 18: Power curve for straight type at 30° folding angle and for 10 m/s

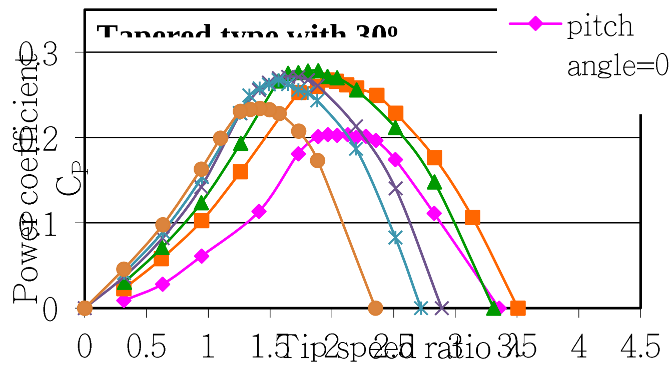

Figure 19: Power curve for tapered type at 30° folding angle and for 10 m/s

3.2 Wind Tunnel Testing Of the Two Straight Folding Lines Blades

From the power curves in figure 11 to figure 19 shows that the at wind speed of 10 m/s. For the inversely tapered type blades, we examined the performance of them with two straight folding lines whose angles are selected from 5, 10, 15 and 20[deg]. Blade pitch angles are also changed at 0, 5, 10, 15, 20 and 25[deg].

The result shows the maximum power coefficient is 0.372 when two folded lines whose angle are 5[deg], 10[deg] parallel the forward edge (type 3) with blade pitch angle of 20[deg].

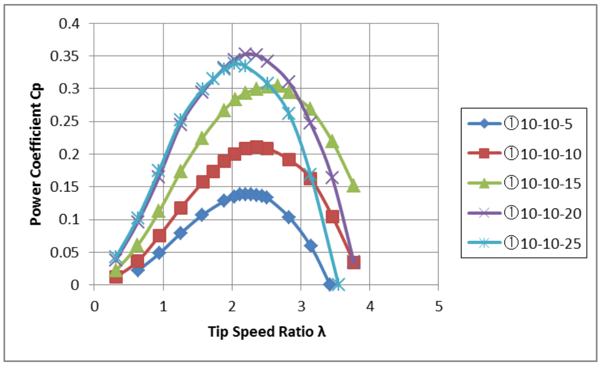

Figure 20: Power curve for Type 1 at 10º and 10º folding angle and for 10 m/s

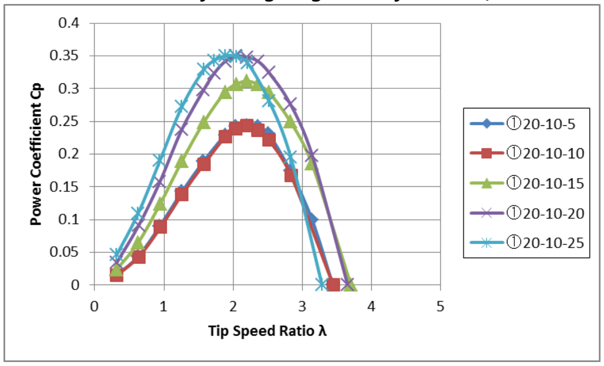

Figure 21: Power curve for Type 1 at 20º and 10º folding angle and for 10 m/s

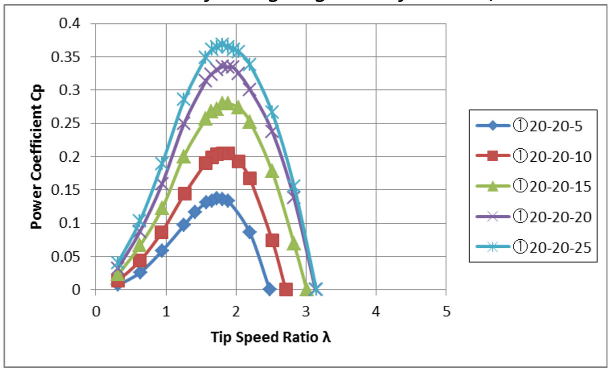

Figure 22: Power curve for Type 1 at 20º and 10º folding angle and for 10 m/s

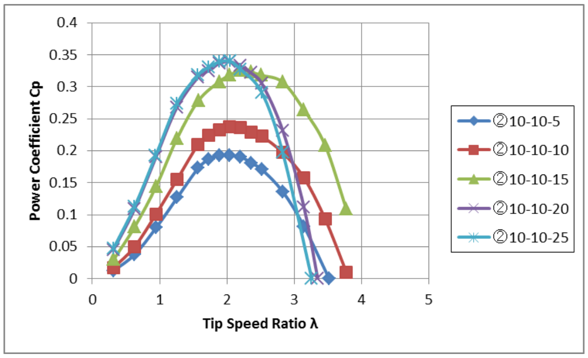

Figure 23: Power curve for Type 2 at 10º and 10º folding angle and for 10 m/s

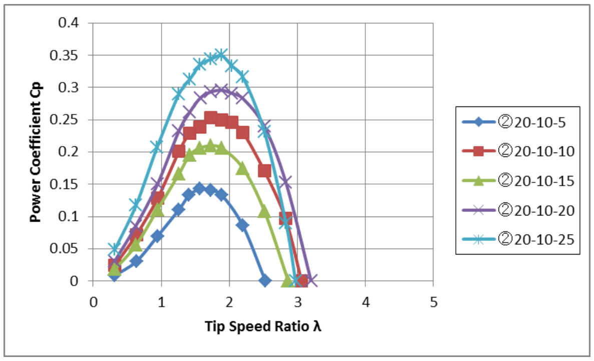

Figure 24: Power curve for Type 2 at 20° and 10° folding angle and for 10 m/s

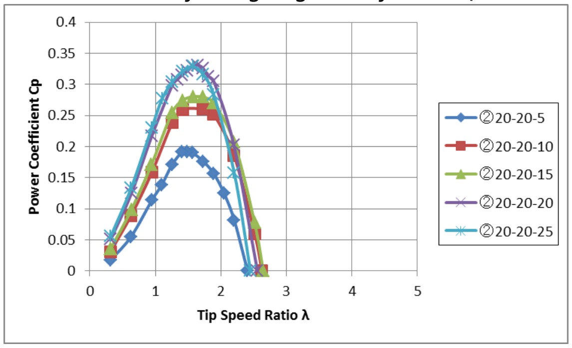

Figure 25: Power curve for Type 2 at 20° and 20° folding angle and for 10 m/s

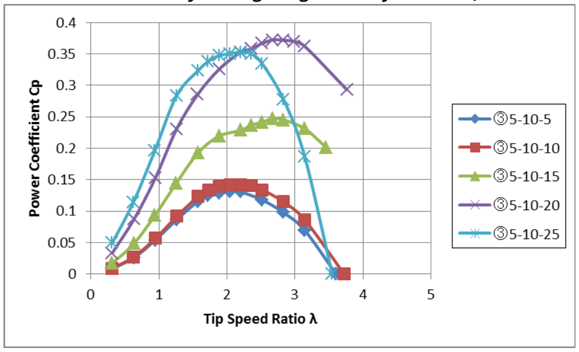

Figure 26: Power curve for Type 3 at 5° and 10° folding angle and for 10 m/s

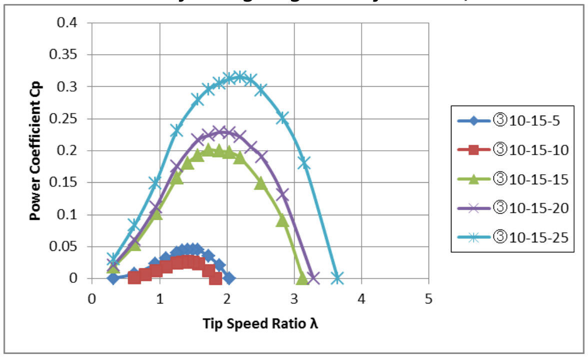

Figure 27: Power curve for Type 3 at 10° and 15° folding angle and for 10 m/s

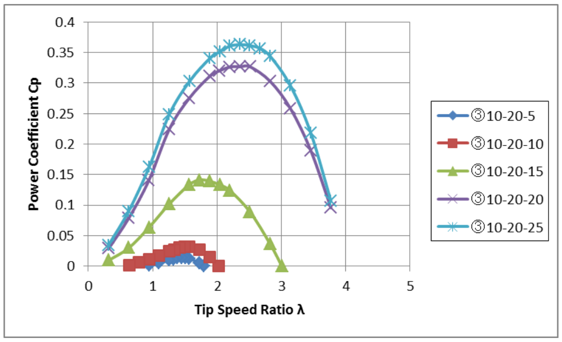

Figure 28: Power curve for Type 3 at 10º and 20º folding angle and for 10 m/s

4.0 Conclusion

(i). In this experiment, the maximum power coefficient for tapered type is Cpmax=0.278 when folding angle is 30[deg] and blade pitch angle is 10[deg]. The straight type gave Cpmax=0.303 when folding angle is 30[deg] and blade pitch angle is 15[deg] while the inversely tapered type gave Cpmax=0.3377 when folding angle is 30[deg] and blade pitch angle is 15[deg]. Therefore the most efficient model was inversely tapered type.

(ii). The maximum power coefficient is 0.372 when two folded lines whose angle are 5[deg], 10[deg] parallel the forward edge (type 3) with blade pitch angle of 20[deg].

(iii). The simplified blade for small wind turbine showed very high performance compared to precisely designed blades therefore, the folded plate bladed rotors will have good prospect not only for developing countries but also for advanced nations.

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